REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
06-09-2003	Final Technical Report	12/1/2002-11/30/2003

4. TITLE AND SUBTITLE
Symposium Q: Magnetoelectronics - Novel Magnetic Phenomena In Nanostructures

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-03-1-0202

5c. PROGRAM ELEMENT NUMBER

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Materials Research Society
506 Keystone Dr
Warrendale PA 15086

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
800 N Quincy St
Arlington VA 22217-5660

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution limitation - None

13. SUPPLEMENTARY NOTES
None

14. ABSTRACT
Attached

20030612 114

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
N/A	N/A	N/A	None	16	Donna J. Gillespie, Symposium Fund Administrator / 724-779-3004 Ext 202/gillespie@mrs.org

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Magnetoelectronics of Nanostructures Sports
Healthy Debate
(See MRS Proceedings Volume 746)

The area of anisotropic magnetotransport in magnetic superlattices (see Figure 1) remains controversial and intensely investigated by theorists and experimentalists, as demonstrated in Symposium Q on Magnetoelectronics—Novel Magnetic Phenomena in Nanostructures. The main issues that were highlighted are the importance of mean free path, the connection between structure and GMR, and whether GMR originates from the bulk or interface in the superlattice, especially in experiments in which the current flows perpendicular to the interfaces. B.J. Hickey (Leeds Univ.) said, based on experiments in Permalloy-containing superlattices, that the mean free path is crucial in determining the GMR. Theoretical work (P. Weinberger, Univ. of Vienna) seems to show that in the Fe/Cr interface, scattering originates in the interface in agreement with experimental claims (J. Santamaria, Univ. of Madrid, Spain).

The magnetic proximity effect, while an old subject, has received renewed attention from experimentalists and theorists who are principally motivated by the developments in spintronics. M. Kiwi (Catholic Univ., Chile) summarized the long history of this field. Generally, it is accepted and found experimentally (A. Hoffmann, ANL) that the magnetic proximity effect is small and confined to a very short distance close to the interface. A novel type of proximity effect was predicted theoretically (L.J. Sham, UCSD) in which electrons in a semiconductor become polarized if reflected from an interface with a magnetic material.

Exchange bias, while discovered almost 50 years ago, is still mysterious and thus intensely investigated. The exact origin, whether there is a single mechanism, and the connection to other physical and structural properties are researched by many groups worldwide, especially in antiferromagnetic/ferromagnetic (AF/F) bilayers. E.D. Dahlberg (Univ. of Minnesota) gave criteria for the magnetization reversal in MnF2/Fe bilayers and discussed the connection between reversal asymmetry and a threefold magnetic anisotropy found in this system. This is very unusual since most magnetic materials exhibit a symmetric reversal mechanism. M.D. Stiles (NIST) elaborated on the origin of the coercivity enhancement in polycrystalline AF/F bilayers. The random orientation of the AF easy direction from grain to grain yields an inhomogeneity and frustration of the F magnetization during reversal that enhances the coercivity. C. Leighton (Univ. of Minnesota) could experimentally demonstrate that the critical AF-layer thickness below which the exchange bias breaks down scales with the AF anisotropy. T.C. Schulthess (ORNL) discussed a theoretical model in which the symmetry of the 90° AF/F coupling is broken by introducing an anisotropic exchange term (Dzyaloshinskii–Moriya interaction), which accounts for different random interfacial exchange configurations.

Symposium Support: ARO and ONR.

SYMPOSIUM Q

Magnetoelectronics—Novel Magnetic Phenomena in Nanostructures

December 1 – 5, 2002

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Symposium Support
Army Research Office
Foundation Advanced Technology Institute, Japan
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to be published in both book form and online
(see *ONLINE PUBLICATIONS* at www.mrs.org)
as Volume 746
of the Materials Research Society
Symposium Proceedings Series**

* Invited paper

TUTORIAL

FT Q: MAGNETOELECTRONICS AND NOVEL MAGNETIC PHENOMENA IN NANOSTRUCTURES

Sunday, December 1, 2002
10:00 a.m. - 5:00 p.m.
Room 209 (Hynes)

This tutorial will provide an introduction to the structural, magnetic, and transport properties of artificially engineered magnetic structures, consisting of tunneling devices, superlattices, molecular nanomagnets, and other nanostructures. A focus will be on the phenomena of giant magnetoresistance (GMR), tunneling magnetoresistance (TMR), magnetic quantum tunneling, spin-dependent transport in confined geometries, exchange bias, current-induced magnetic moment rotations and non-equilibrium spin transfer in metal systems. The speakers will coordinate their presentations to cover these topics, providing background information, a discussion of central theoretical ideas and experimental results, and the current state of the art in materials and devices. The tutorial will also include discussion of applications to magnetic field sensors, magnetic recording, and MRAM. The intention of the tutorial is to give attendees a basic and broad introduction to this rapidly moving field of materials research.

Instructors:
Sadamichi Maekawa, Tohoku University
Stuart S.P. Parkin, IBM Almaden Research Center
Dan Ralph, Cornell University
Chris Leighton, University of Minnesota
David Hendrickson, University of California, San Diego

SESSION Q1: MAGNETIC SYSTEMS

Chairs: Teruya Shinjo and Andrew D. Kent
Monday Morning, December 2, 2002
Room 209 (Hynes)

8:30 AM *Q1.1
HALF-INTEGER SPIN MOLECULAR NANOMAGNETS. David N. Hendrickson, Sheila M.J. Aubin, Ziming Sun, University of California at San Diego, Dept. of Chemistry, La Jolla, CA; Wolfgang Wernsdorfer, Laboratoire L. Neél, Grenoble, FRANCE; George Christou, Sumit Bhaduri, Núria Aliaga-Alcalde, University of Florida, Dept. of Chemistry, Gainesville, FL.

Single-molecule magnets (SMMs) function as single-domain nanomagnets that exhibit hysteresis in the response of magnetization versus external magnetic field. Steps are observed in the magnetization hysteresis loops of SMMs at intervals of the magnetic field [1]. These steps are manifestations of quantum tunneling of magnetization at the mesoscopic level. If SMMs are to be employed as a small magnetic memory unit or in quantum computation, it is important to both understand and control quantum magnetization tunneling. Half-integer spin SMMs provide interesting possibilities for magnetization tunneling not found in integer-spin SMMs. In zero magnetic field, the quantized states of a half-integer spin SMM occur in Kramers degenerate pairs. Magnetization tunneling between a Kramers degenerate pair is not allowed in zero field. Mn_4 ($S = 9/2$) and Mn_{12} ($S = 19/2$ and $21/2$) SMMs have been characterized as having half-integer spin electronic ground states. Data are presented for these SMMs to examine the issue of magnetization tunneling at zero magnetic field. The Landau-Zener method is used to measure the tunneling splitting as a function of transverse field [2]. Spin-parity dependent tunneling is established by comparing the transverse field dependence of the tunneling splitting of integer and half-integer spin SMMs. It is also shown how an antiferromagnetic exchange interaction between two SMMs leads to an exchange biasing of the magnetic field at which magnetization tunneling occurs in one of the coupled SMMs [3]. [1] G. Christou, D. Gatteschi, D.N. Hendrickson, and R. Sessoli, *MRS Bulletin*, **25**, 66 (2000) [2] W. Wernsdorfer, S. Bhaduri, C. Boskovic, G. Christou, and D.N. Hendrickson, *Phys. Rev. B*. **65**, 180403(R) (2002). [3] W. Wernsdorfer, N. Aliaga-Alcade, D.N. Hendrickson, and G. Christou, *Nature* **416**, 406 (2002).

9:00 AM *Q1.2
MAGNETIC STRUCTURES AND MAGNETORESISTANCE OF MAGNETIC NANODOTS AND NANOWIRES. Ko Mibu, Kyoto Univ, Research Center for Low Temperature and Materials Sciences, Uji, JAPAN; Takuya Okuno, Kousaku Miyake, Kyoto Univ, Institute for Chemical Research, Uji, JAPAN; Kunji Shigeto, RIKEN, Frontier Research System, Wako, JAPAN; Teruo Ono, Osaka Univ, Graduate School of Engineering Science, Toyonaka, JAPAN; Teruya Shinjo, International Institute for Advanced Studies, Kizu, JAPAN.

Magnetic nanodots and nanowires were prepared by means of electron-beam lithography and lift-off technique. The magnetic structures were controlled by engineering the size and shape of the nanopatterns. It was demonstrated that two types of magnetic vortex structures, i.e., circular vortex and antivortex, are formed in circular, asteroid, and rectangular patterns made of soft magnetic NiFe films. A spot with perpendicular magnetization, i.e., turned-up or turned-down magnetization, at the center of both types of vortices, was observed by magnetic force microscopy (MFM). The magnetization reversal process of these magnetic singularity-spots with ca. 10 nm in diameter was studied through MFM observations and micromagnetics simulations. The magnetization processes of nanodots were also monitored through anisotropic magnetoresistance effect. The concept to control magnetic structures by nanostructural engineering was applied to wire systems as well. A magnetic domain wall with a well-defined internal magnetic structure was successfully confined at a nanocontact between two magnetic wires. The magnetoresistance was measured in order to find large magnetoresistance effect and novel transport phenomena caused by the existence of a domain wall. The results on magnetoresistance measurements for other wire systems will also be shown briefly.

9:30 AM *Q1.3
DEFECTS, TUNNELING AND EPR. Kyungwha Park, Florida State Univ, Dept of Chemistry and School of Computational Science and Information Technology (CSIT), Tallahassee, FL; M.A. Novotny, Mississippi State Univ, Dept of Physics and Astronomy, Mississippi State, MS; N.S. Dalal, Florida State Univ, Dept of Chemistry, Tallahassee, FL; S. Hill, Univ of Florida, Dept of Physics, Gainesville, FL; P.A. Rikvold, Florida State Univ, CSIT, Dept of Physics and Center for Materials Research and Technology, Tallahassee, FL.

Single-molecule magnets (SMMs) consist of identical nanoscale, single-domain magnetic molecules, each of which has a large effective spin and a large crystal-field anisotropy. Despite a large effective spin, SMMs show quantum tunneling between the spin-up and spin-down states and quantum coherence. So far the origin of the macroscopic quantum tunneling for SMMs has not yet been fully understood. Our theoretical analysis on electron paramagnetic resonance (EPR) spectra for SMMs may shed light on the tunneling mechanism. Considering possible defects in samples and small intermolecular exchange and dipole interactions, we calculate line widths, line shifts, and line shapes of EPR spectra as functions of resonance frequency, energy level, and temperature, and compare them with experiment.

10:30 AM *Q1.4
SINGLE CRYSTAL EPR SPECTROSCOPY OF SINGLE MOLECULE MAGNETS. Stephen Hill, University of Florida, Dept. of Physics, Gainesville, FL; Naresh Dalal, Florida State University, Dept. of Chemistry and NHMFL, Tallahassee, FL, Kyungwha Park, Florida State University, Dept. of Physics and CSIT, Tallahassee, FL; George Christou, University of Florida, Dept. of Chemistry, Gainesville, FL; David Hendrickson, University of California at San Diego, Dept. of Chemistry, La Jolla, CA; Andrew Kent, New York University, Dept. of Physics, New York, NY.

We report high frequency electron paramagnetic resonance (EPR) investigations of a series of high spin (total spin up to $S = 10$) manganese, cobalt and nickel complexes which have been shown to exhibit single molecule magnetism, including low temperature (below $\sim$ 1K) hysteresis loops and resonant magnetic quantum tunneling. A cavity perturbation technique enables high-sensitivity oriented single crystal EPR measurements spanning a very wide frequency range (16 to 200 GHz). Fitting of the frequency and field orientation dependence of EPR spectra allows direct determination of the effective spin Hamiltonian parameters. Studies on a range of materials with varying (approximately axial) site symmetries facilitates an assessment of the role of transverse anisotropy (terms in the Hamiltonian that do not commute with S_z) in the magnetic quantum tunneling phenomenon. We also examine quantitatively the temperature dependence of the EPR linewidths and line shifts, for fixed frequency measurements with an applied magnetic field along the easy axis. Simulations of the obtained experimental data take into account intermolecular spin-spin interactions (dipolar and exchange), as well as distributions in both the uniaxial anisotropy parameter D and the Landé g-factor. These findings could have important implications for the mechanism of quantum tunneling of magnetization in these single molecule magnets.

11:00 AM *Q1.5
THE EXTRAORDINARY HIGH ROOM TEMPERATURE SPIN POLARIZATION OF EPITAXIAL $CrO_2(100)$ AND $Fe_3O_4(111)$ THIN FILMS. U. Rüdiger, Y. Dedkov, M. Fonine, C. König, and G. Güntherodt, II. Physikalisches Institut, RWTH Aachen, GERMANY.

The intriguing feature of the materials class of half-metallic ferromagnets (HMF) is metallic conductivity for one spin component and insulating behavior for the other one. This was in most cases theoretically predicted on the basis of spin-polarized electron band structure calculations. The theoretically predicted 100% spin polarization at E_F of HMFs make them promising materials for magnetoeletronic and spintronic devices. The spin-dependent electronic structure of thin epitaxial films of $Fe_3O_4(111)$ and $CrO_2(100)$ has been investigated at room temperature by means of spin-, energy-, and angle-resolved photoemission spectroscopy. The structural properties of the epitaxial Fe_3O_4 and CrO_2 films have been analyzed by LEED, STM, XRD and TEM. Epitaxial $Fe_3O_4(111)$ films have been grown on W(110) and $Al_2O_3(11\bar{2}0)$ substrates by oxidizing epitaxial Fe(110) films. These films show near the Fermi energy E_F a spin polarization of $-(80 \pm 5)$% at room temperature [1]. The spin-resolved photoemission spectra using $h\nu = 21.2 eV$ show for binding energies between $1.5 eV$ and E_F good agreement with binding energies of spin-split band states from density-functional calculations. Epitaxial $CrO_2(100)$ films have been deposited on $TiO_2(100)$ substrates by a chemical vapor deposition (CVD) technique. An extraordinary high spin polarization of about (95 ± 5)% was found at the Fermi energy E_F at room temperature [2]. After extended sputtering (750 *sec.*) the spin polarization vanishes but can be recovered from about +10% up to 85% upon annealing at 150°*C*. This would allow an ex situ CVD preparation of CrO_2 films for implementing them in magnetoelectronic devices.

[1] Yu. D. Dedkov, U. Rüdiger, and G. Güntherodt, Phys. Rev. B **65**, 064417 (2002).
[2] Yu.S. Dedkov, M. Fonine, C. König, U. Rüdiger, G. Güntherodt, S. Senz, and D. Hesse, Appl. Phys. Lett. **80**, 4181 (2002).

11:30 AM Q1.6

STRUCTURE AND MAGNETIC PROPERTIES OF ULTRATHIN EPITAXIAL $La_{0.7}Ca_{0.3}MnO_3$ FILMS: STRAIN VERSUS FINITE SIZE EFFECTS.

A. de Andres[a], J. Rubio[b], G. Castro[a,b], S. Taboada[a], C. Prieto[a], J.L. Martinez[a], J. Colino[c], M. Garcia-Hernandez[a], M. Varela[d], J. Santamaria[d]; [a]Instituto de Ciencia de Materiales de Madrid-CSIC, SPAIN; [b]ESRF, Grenoble, FRANCE; [c]Universidad de Castilla-la-Mancha, SPAIN; [d]Dept. Fisica Aplicada III, Universidad Complutense de Madrid, SPAIN.

Tunneling magnetoresistance, in manganese perovskite based spin valves, decreases strongly with temperature, being almost zero near T_c. This is a strong drawback for the exploitation of these half metallic systems. The study and understanding of the magnetic properties of interfaces and ultrathin manganite layers are, therefore, essential. We present a detailed structural, morphological and magnetic study of $La_{0.7}Ca_{0.3}MnO_3$ films grown by dc sputtering on $SrTiO_3$ substrates. The thickness of the studied films ranges between 2.4nm and 27 nm. The obtained films, after an annealing at 800 C, are coherently strained epitaxial layers. The surface presents monolayer steps with a mean roughness of about 0.4 nm for all the films. High resolution TEM images show coherent clean substrate-manganite interface. Surface X-ray diffraction experiments, performed on 2.4, 6.6, 15 and 27 nm films, have allowed us to obtain the symmetry and parameters of the films. The quasicubic orthorhombic structure of the bulk material adopts a 2x2 square lattice referred to the $SrTiO_3$ substrate in the film plane, while the out of plane parameter maintains the bulk value. The unit cell volume is therefore larger than the bulk value but almost constant in the 2.4 to 27 nm range. While no structural changes are detected, the ferromagnetic transition temperature decreases drastically as the layer thickness is reduced. The behavior of the saturation magnetization and of the resistivity, varying the layer thickness, shows that there is no dead layer from the magnetic nor the transport points of view. The reduction of the Curie temperature is explained by the limitation of the divergence of the spin-spin correlation length by the finite thickness of the films. The functional dependence indicates the validity of the mean field approximation and a mean spin-spin interaction range of about 5nm.

11:45 AM Q1.7

INTERFACIAL INTERACTIONS IN FRACTIONAL-LAYER OXIDE SUPERLATTICES.

Naoyuki Nakagawa, Mikk Lippmaa, Keisuke Shibuya, Univ of Tokyo, Inst for Solid State Materials, Kashiwa, JAPAN; Hideomi Koinuma, Tokyo Inst of Tech, Materials and Structures Lab, Yokohama, JAPAN; Masashi Kawasaki, Tohoku Univ, Inst for Materials Research, Sendai, JAPAN.

It is important to understand the interactions at the interfaces between superlattice layers and/or substrates. The volume and discontinuity of the interfaces affect the physical properties of superlattices, because the properties of the interface layers are different from those of bulk films. Fractional-layer superlattices, composed of layers of nanodots embedded periodically in a matrix material, offer a convenient way to control the volume of interfaces by changing the size and the 2D or 3D density of embedded nanodots. We have used such lattices to study magnetic interactions at the interfaces of manganese oxides. Fractional-layer oxide suprlattices were grown on $SrTiO_3$ substrates by pulsed laser deposition while controlling each layer thickness on an atomic scale. Ferromagnetic metallic $La_{0.6}Sr_{0.4}MnO_3$ (LSMO) and G-type antiferromagnetic insulator $La_{0.6}Sr_{0.4}FeO_3$ (LSFO) were adopted as matrix layers and nanodots, respectively. A large magnetoresistance effect was observed when the nanodot density was adjusted so that the lattice was close to a percolative conduction threshold In order to investigate magnetic interactions at the interfaces further, LSMO ($x = 0.2$ or $x = 0.4$) / LSFO ($x = 0$ or $x = 0.4$) fractional-layer suprlattices were fabricated with various combinations of the doping level x. Magnetoresistance was only observed when nanodots were embedded in LSMO $x = 0.4$ layers but not when LSMO $x = 0.2$ was used. This indicates that the contribution of direct exchange interactions at the interfaces are quite small and the charge transfer effect is more important. In case of the LSMO ($x = 0.2$) superlattices, an effective increase of x in the LSMO layers would still leave the material in the ferromagnetic state, whereas, in the LSMO ($x = 0.4$) superlattices, the increase of x in the LSMO layer from the nominal value of $x = 0.4$ brings the system close to the phase transition boundary at $x = 0.5$.

SESSION Q2: MAGNETIC MULTILAYERS

Chairs: Jagadeesh S. Moodera and Hanns-Ulrich J. Habermeier
Monday Afternoon, December 2, 2002
Room 209 (Hynes)

1:30 PM Q2.1

EXPLORING MICROMAGNETIC INTERLAYER COUPLING BY LAYER-RESOLVED MAGNETIC MICROSCOPY.

Wolfgang Kuch, L.I. Chelaru, K. Fukumoto, F. Offi, X. Gao, M. Kotsugi, J. Kirschner, Max-Planck-Institut für Mikrostrukturphysik, Halle, GERMANY.

Besides the globally observable indirect interlayer exchange coupling, locally acting micromagnetic interlayer coupling mechanisms become increasingly important as the size of magnetic elements is reduced. The latter include the magnetostatic interaction between fringe fields from magnetic domain walls. It has been suggested that such an interaction could be responsible for several phenomena, including the irreversible reduction of magneto-resistance in magnetic multilayers after application of an external field [1] or the creeping loss of remanent hard layer magnetization in hard/soft spin valve elements upon soft layer cycling [2]. Photoelectron emission microscopy (PEEM) using x-ray magnetic circular dichroism (XMCD) as element-selective magnetic contrast mechanism is ideally suited to study such micromagnetic effects in magnetic interlayer coupling, since the direct comparison of the layer-resolved domain images of different magnetic layers directly visualizes the different types of magnetic interaction between these layers. We present a layer-selective XMCD-PEEM study of single-crystalline Co/Cu/Ni trilayers, epitaxially grown in-situ as micrometer-sized crossed wedges on a Cu(001) single-crystal substrate. The competition between the magnetic anisotropy energies of each magnetic layer and the interlayer exchange coupling leads to reorientation transitions between collinear and non-collinear magnetization states. An influence of the magnetic stray fields of Ni domain walls on the Co magnetization is also evident in the images. This first direct imaging of domain-wall stray field interaction by layer-resolved XMCD-PEEM proves indeed the existence of such a coupling mechanism. Quantitative estimates of its strength are derived from applying external magnetic fields. [1] J. A. Borchers et al., Phys. Rev. Lett. 82, 2796 (1999). [2] S. Gider et al., Science 281, 797 (1998).

1:45 PM Q2.2

DOMAIN WALL MAGNETORESISTANCE AND COMPLEX MAGNETIC RESPONSE IN ANTIFERROMAGNETICALLY COUPLED Fe/Cr MULTILAYERS.

Farkhad Aliev, Raul Villar, Dpto. de Fisica de la Materia Condensada, C-III, Universidad Autonoma de Madrid, SPAIN; Rainer Schad, CMIT, University of Alabama, Tuscaloosa, AL; Jose Luis Martinez, ICMM-CSIC, Cantoblanco, Madrid, SPAIN.

For antiferromagnetically coupled [Fe/Cr]10 multilayers the low field contribution to the resistivity, which is caused by the domain walls (DWs), is strongly enhanced at low temperatures. The low temperature resistivity increases according to a power law with the exponent 0.7-1. This behavior can be explained by suppression of anti-localization effects by the nonuniform gauge fields caused by the domain walls [1]. Analyses of complex low frequency (f=3-10000Hz) magnetic susceptibility in [Fe/Cr]n (n=10-50) multilayers shows on strong enhancement of the magnetic losses at low magnetic fields (H<50 G), which may be related to the AC field induced (DWs) movement. For frequencies 100Hz<f<1000Hz at temperatures below 10K, this hysteretic low field peak in the magnetic losses transforms to a non-hysteretic dip, indicating a possible qualitative change in the dynamics of the (DWs). We relate the observed non-trivial response at low fields and low temperatures to possible quantum nucleation and depinning of the domain walls [2]. The frequency dependence of the dissipation at small non-zero magnetic fields, at lowest temperature (T=2K), may be reasonably well fitted by the expression that describes the losses of a damped oscillator with single relaxation time of about 0.0003 sec. [1] F.G. Aliev, at al., submitted. [2] F.G. Aliev, at al., Phys. Rev. Lett., v 88, p 187201 (2002).

2:00 PM Q2.3

STRUCTURAL, MAGNETIC AND MAGNETORESISTIVE PROPERTIES OF THE ELECTROCHEMICALLY DEPOSITED ARRAYS OF Co NANOWIRES AND Ag-Co NANOMULTILAYERS. H.R. Khan[a,b] and K. Petrikowski[b]; [a]FEM, Materials Physics Department, Schwaebisch Gmuend, GERMANY; [b]Department of Physics, University of Tennessee, Knoxville, TN.

The fabrication of nanosized ferromagnetic particles,wires and multilayers and their properties such as coercivity (Hc), squareness (Mr/Ms) and anisotropic magnetization, and GMR is important for the applications in high density perpendicular and quantum storage media and micromagnetic sensors(1,2). The isolated nanosized 18 nm diameter arrays of the nanowires of Co and Ag-Co nanomultilayers are electrodeposited in the pores of anodic alumina. The morphology, crystal strucure, as well as magnetic and magnetoresistive properties of these arrays are investigated. The Co nanowires consist of hcp phase with c-axis orientation perpendicular to the substrate surface and have an enhanced easy axis Hc value of 1549 Oe and Mr/Ms-ratio of 0.96.Whereas the Ag-Co nanomultilayers show Hc value of 464 and Mr/Ms.of.0.24. The magnetic and structural properties of the nanowires and nanomultilayer arrays are compared with the continuos electrodeposited Co film. The GMR data of nanomultilayer arrays will also be dicussed. 1. H.R. Khan and K. Petrikowski; J. Magn Magn. Materials 215-216 (2000) 526-528; 2. H.R. Khan and K. Petrikowski; Materials Science and Engineering C19(2002)345-348 This work was supported by the Bundesministerium für Wirtschaft under the grant no.AIF-11429.

2:15 PM Q2.4

AB INITIO STUDY OF CPP TRANSPORT IN Fe/Cr/Fe TRILAYERS: INFLUENCE OF INTERDIFFUSION AND INPURITIES. Heike C. Herper, Peter Entel, Gerhard-Mercator University, Dept of Theoretical Physics, Duisburg, GERMANY; Peter Weinberger, TU Vienna, CMS, Vienna, AUSTRIA; Laszlo Szunyogh, Budapest Univ, Dept of Theoretical Physics, Budapest, HUNGARY.

We have investigated the giant magnetoresistance (GMR) and the interlayer exchange coupling (IEC) of Fe(001)/Cr/Fe(001) trilayers with respect to interface alloying. In addition, the influence of extended transition metal impurities (layers) is discussed. We are able to show that the periodicity of the GMR is directly influenced by the IEC. Furthermore, it is observed that the behavior of the IEC and the magnetic moments strongly depend on whether an impurity overlayer or Cr-impurity alloys are used. It turns out that the size of the GMR is only little effected by interdiffusion or impurities, which is in agreement with the experimental findings. The electronic and magnetic properties of the trilayers are investigated within the fully relativistic, spinpolarized SKKR method and the LDA, the transport properties of the Fe/Cr/Fe systems from the fully relativistic spinpolarized Kubo-Greenwood equation.

2:30 PM Q2.5

MICROSTRUCTURE AND MAGNETIC PROPERTY OF L1o CoPt-20at. %C MAGNETIC THIN FILM. Dong Yean Oh, Joong Keun Park, Dept of Materials Science and Engineering, Korea Advanced Institute of Science and Technology, Daejeon, KOREA.

The multi-layers of (CoPt/C/CoPt)n structure were deposited by RF magnetron sputter on an oxidized Si substrate in order to incorporate carbon of about 20at.% into CoPt film. They were annealed at 650°C in a vacuum furnace to transform the film into L1o CoPt-C film. The TEM investigation showed that the insertion of C-layer into CoPt film greatly retarded the grain growth rate of L1o CoPt film during transformation treatment and that the retardation power increased with the number of divided carbon layers in the multi-layer structures. The stable grain structure of the average grain size of 12nm was obtained by reducing the thickness of each C-layer to less than about 10Å. Study using HRTEM indicated that the reducing the thickness of each carbon layer greatly enhanced the interlayer atomic mixing mostly through the grain boundary diffusion during sputter deposition at R.T. The thin carbon film formed along grain boundary during deposition is largely responsible for the retardation of grain growth of L1o CoPt thin film on transformation annealing. The measurement of magnetic property using VSM showed that both the coercivity and Mrt were significantly reduced as a result of carbon incorporation into L1o CoPt film. This suggested the occurrence of a significant amount carbon mixing with CoPt solid solution during transformation annealing. The signal to noise ratio (SNR) is expected to be also increased from the examination of the variation of the coercivity squareness. A quantitative estimation of the SNR variation is currently being under investigation by measuring ΔM variation.

2:45 PM Q2.6

DEGRADATION OF Fe / Cu MULTILAYERS. Jörg Ebert, Mohammad Ghafari, Branko Stahl, and Horst Hahn Darmstadt University of Technology, Institute of Materials Science, Thin Films Division, Darmstadt, GERMANY.

Since the discovery of the Giant Magnetoresistance effect (GMR) there has been great effort to utilize it for industrial applications. Though the computer industry already applies Spin-Valve systems in read heads of hard disc drives the automotive suppliers still have to cope with fulfillment of the strict specifications of high temperature usage in automobiles. One suggestion is to use antiferromagnetically coupled multilayers based on Co and Cu. To reduce undesirable hysteresis Co is alloyed with Fe. As a side effect the presence of Fe enables studying the local microstructure and magnetic ordering by Moessbauer spectroscopy. This provides the chance to reveal the origins of the annealing behavior of GMR systems. Representing a basic system a trilayer consisting of Cu / Fe / Cu was prepared by molecular beam epitaxy (MBE) using 57Fe. The sample was annealed in vacuum at a temperature of T = 230°C for 1 hour. Moesbauer spectra of the as prepared as well as of the annealed sample show the changes in the microstructure due to diffusion, grain growth, and interface smoothening. To link these observations to magnetoresistive properties multilayers of the following type were analyzed: Si / SiO2 / [Fe (1,5 nm) / Cu (x nm)]*20 (2,0 nm $< x <$ 3,1 nm). The field dependence of the electrical resistivity was quantified by the standard four point probe technique before and after heat treatment. To complete the information on the changes, measurements of the magnetization curves were carried out with a SQUID magnetometer and the development of crystallinity was investigated by x-ray diffraction.

3:30 PM Q2.7

RELATIVISTICALLY INDUCED NON-COLLINEAR MAGNETISM IN PERMALLOY. Markus Eisenbach, Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, TN; D.M. Nicholson, Computer Science and Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, TN; G. Malcolm Stocks, Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, TN.

Permalloy (fcc solid solution $Ni_cFe_{(1-c)}$ $c \sim 0.8$) is a major component in modern magnetic multilayers used in Giant Magneto-resistance (GMR) devices. Despite the great interest in the spin transport properties of this system, they are still not understood. State of the art first principles calculations of the residual resistivity yield a value that is too small, despite attempts to include as much of the important physics as possible. The small resistivity results from a short circuit in one of the spin channels caused by a rather precise band alignment for that channel. A novel suggestion for additional scattering is the existence of non-collinear magnetism. Here we present calculations of the magnetic structure of large super-cell models of permalloy using the Locally Self-consistent Multiple Scattering (LSMS) method. Treated non-relativistically we find a collinear arrangement of the moments to be the ground state. In a fully relativistic treatment we find the ground state to be non-collinear, all be it that the non-collinearity is small. We discuss these results in the light of the work of Sandratskii [Phys. Rev. B 64, 134402, (2001)] relating non-collinearity to an underlying lack of symmetry. This work is supported by the DOE-OS through BES-DMSE and OASCR-MICS under contract number DE-AC05-00OR22725 with UT-Battelle LLC. Calculations are performed at CCS-ORNL and at NERSC.

3:45 PM Q2.8

BATCH-FABRICATION OF SUB-100NM SPIN-VALVE JUNCTIONS FOR SPIN-CURRENT-INDUCED MAGNETIC EXCITATION STUDIES. J.Z. Sun, D.J. Monsma[†], D.W. Abraham, M.J. Rooks, and R.H. Koch, IBM T.J. Watson Research Center, Yorktown Heights, NY; [†]IBM Almaden Research Center. Present Address: Physics Department, Harvard University, Cambridge, MA.

A method is developed for the fabrication of sub-100nm current-perpendicular spin-valve junctions with low contact resistance. The approach is to use a batch-fabricated trilayer template with the junction features defined by a metal stencil layer and an undercut in the insulator. The spin-valve thin film stack is deposited afterwards into the stencil, with the insulator undercut providing the necessary magnetic isolation. Using this approach, reproducible spin-current induced magnetic switching is demonstrated for junctions down to 50nm x 100nm in size. Junctions thus fabricated were used to study the spin-current-induced magnetic excitation including magnetic switching. Results can be understood in terms of the transfer of spin-angular-momentum between adjacent magnetic layers under the passage of a spin-polarized electric current.

4:00 PM Q2.9

LOW FREQUENCY NOISE AND DOMAIN WALL DYNAMICS IN Co/Al2O3/Ni80Fe20 TUNNEL JUNCTIONS. Ruben Guerrero, Vladimir Pryadun, Farkhad Aliev, Raul Villar, Dpto. Fisica Materia Condensada, Universidad Autónoma de Madrid, SPAIN, and J. Moodera, Massachusetts Institute of Technology, Boston, MA.

We shall present measurements of noise power spectrum (0.005-2Hz) in the transport response for Co/Al2O3< *Fe* >/Ni80Fe20 MTJs and with applied bias up to 300mV. Dynamics of magnetization reversal of the electrodes was detected both from DC resistive time response and by using modulation technique. We link the magnetic response to the depinning of domain walls of the electrodes. In addition, we also observed noise, which is independent of the magnetic field, indicating its relation to the trapped charges inside the insulating barrier. Dependence of the noise power spectrum on the applied bias in the ferro and antiferromagnetic configurations will be discussed. We will also present a technique which allows following complex magnetic response in GMR materials via analyses of the in-phase and out-of phase transport under weak modulation (1-200 Hz) of the DC magnetic field. While the real part of the AC response reflects the derivative dR/dH, the imaginary response depends on magnetic losses. We shall compare transport magnetic response with DC magnetization and complex AC susceptibility directly measured for MTJs. The difference in AC response could be attributed to the fact that AC transport probes MTJ's cross area and mainly depends on the interface magnetic losses, while direct magnetic measurements involve also leads and are sensitive both to the bulk and surface magnetization dynamics.

4:15 PM Q2.10

BISTABLE MEMORY EFFECT IN CHROMIUM OXIDE JUNCTIONS. A. Sokolov, C.-S.Yang, E. Ovtchenkov, L. Yuan, S.-H. Liou, B. Doudin, University of Nebraska Lincoln, Department of Physics and Astronomy, Brace Laboratory, Lincoln, NE.

Magnetotransport properties of granular CrO_2 films are presented. The CrO_2 crystals are covered by 1-2 nm of insulating Cr_2O_3. Intergrain tunneling characteristics are revealed by making electrical connections to a limited number of grains measured in series and parallel (10 to 15 grains). At lowest temperatures, a well-pronounced zero bias anomaly indicates that impurities in the junctions block the electronic flow and double the magnetoresistance (MR) ratio. Increasing the temperature leads to fast decay of MR value and broadening of zero-bias anomaly. Such a behavior is predicted for Coulomb blockade effect. For zero-field cooled samples, hysteresis in the IV curves are observed at intermediate temperatures. Changing the polarity of a short excitation pulse (100ns) of amplitude smaller than 1 V, triggers a change in the zero-bias resistance by 10-50%, reaching exceptionally ratios up to 2500%. These states are stable and well reproducible in the temperature interval ranging from 150K to 250K. Applying an external magnetic field significantly decreases the IV hysteresis. Explanations are given within the framework of a spin-transfer model, where the polarity of the spin-polarized current controls the magnetic alignment between the chromium oxide crystals and the barrier impurity site. At low temperatures, the current is not sufficient to trigger new magnetization configurations. At temperatures higher than typically 250 K, the bistable states lack time stability. The resistance of the devices in the kW range, the potential high-speed for writing and reading the resistance sate, make these systems interesting candidates for magnetic non-volatile memories using spin-transfer properties.

4:30 PM Q2.11

DIRECT OBSERVATION OF SHUNT EFFECTS IN THE EXTRAORDINARY MAGNETORESISTANCE (EMR) OF MESOSCOPIC VAN DER PAUW PLATES. S.A. Solin†, D.R. Hines and A.C.H. Rowe, NEC Research Institute, Princeton, NJ; J.S. Tsai and Yu. A. Pashkin, NEC Fundamental Research Laboratories, Tsukuba, JAPAN; N. Goel and M.B. Santos, Department of Physics and Astronomy, University of Oklahoma, Norman, OK. †Current Address: Department of Physics, Washington University, St. Louis, MO.

We have recently shown [1] that four-lead externally shunted mesoscopic van der Pauw plates constructed from Si-doped $InSb/Al_{1-x}In_xSb$ quantum well structures exhibit room temperature extraordinary magnetoresistance (EMR) [2]. We have proposed such structures as prototypes of read heads for ultra high density magnetic recording up to areal densities of Tb/in^2. These non-magnetic semiconductor-metal composites do not suffer from the magnetic noise [3] that limits the applicability of conventional read head sensors based on giant MR (GMR) or tunneling MR (TMR). To date, the role of the metallic shunt in boosting the EMR of a mesoscopic structure has been inferred from the results of studies of analogous macroscopic structures [4] but has not been measured directly. Here we compare the EMR of mesoscopic read head prototypes constructed with and without Au shunts and find maximal current sensitivities of 596.5 Ohm/T and 400.0 Ohm/T with corresponding EMR values of 7.5% and 4.9%, respectively at a signal field of 0.05T and a bias of 0.2T. This improvement over our previously reported 147 Ohm/T devices [1] may result from a lowering of leakage current through the quantum well barrier due to the isolation of the contact electrodes with an aluminum oxide layer and a higher barrier resistivity. The above-described EMR devices also exhibit a very large self-biasing zero-field-offset [4] of +0.5T. This offset is considerably larger than that observed in corresponding macroscopic structures. [4]

[1]. S.A. Solin, D.R. Hines, A.C.H. Rowe, J.S. Tsai, Yu A. Pashkin, S.J. Chung, N. Goel and M.B. Santos, Appl. Phys. Lett. **80**, 4012 (2002). [2]. S.A. Solin, Tineke Thio, D.R. Hines and J.J. Heremans, Science **289**, 1530 (2000). [3]. N. Smith and P. Arnette, Appl. Phys. Lett. **78**, 1448 (2001). [4]. T. Zhou, D.R. Hines and S.A. Solin, Appl. Phys. Lett. **78**, 667 (2001).

4:45 PM Q2.12

FERROMAGNETIC SINGLE-ELECTRON TRANSISTOR WITH RC GATE. Jun-ichi Shirakashi, Akita Prefectural University, JAPAN; Yasushi Takemura, Yokohama National University, JAPAN.

Recent progress of nanotechnology to magnetic materials and magnetoresistive devices attracts much attention. The interaction of the electronic charge (single-electron charging effect) and the electronic spin (spin-dependent tunneling effect) is skillfully used in ferromagnetic single-electron transistors (FMSETs) which consist of ferromagnetic tunnel junctions. It is well known for typical FMSET structures that there are two types of devices, capacitively coupled FMSET (C-FMSET) and resistively coupled FMSET (R-FMSET). In both devices, tunnel magnetoresistance (TMR) is modulated by gate and drain voltages, and the possibility as new magnetoresistive nanostructure devices is becoming clear. In this paper, we propose FMSETs coupled to the controlling gate potential by the gate resistance Rg and the gate capacitance Cg in series (RC-FMSETs). Since the current through the Rg may change the effective charge of the central electrode ("island") of the double junction system during the time interval between the tunneling events, several metastable charge states are possible within the Coulomb blockade regime. Therefore, the gate potential and the drain current may exhibit hysteresis. Considering the macroscopic quantum tunneling of charge (q-MQT), we study here transport properties of the electron in the RC-FMSET theoretically. Drain currents and TMR ratio as a function of the drain voltage on the RC-FMSET are calculated using the Monte Carlo method, assuming the double ferromagnetic tunnel junction system with the TMR of 20%. Spin polarization of source, drain and island electrodes can be taken into account by the difference between the tunnel resistances Rp (parallel) and Rap (antiparallel) in each ferromagnetic tunnel junction. Enhancement and hysteresis of the TMR are clearly shown as a function of the drain voltage. This result implies the new functionality of the RC-FMSET.

SESSION Q3: MAGNETOTRANSPORT
Chairs: Shufeng Zhang and Sadamichi Maekawa
Tuesday Morning, December 3, 2002
Room 209 (Hynes)

8:30 AM *Q3.1

AB-INITIO THEORY OF CPP TRANSPORT. Peter Weinberger, Center for Computational Materials Science, Vienna, AUSTRIA.

Theoretical descriptions of electric transport perpendicular to the planes of atoms in two-dimensional translationally invariant systems are reviewed in terms of the Kubo-Greenwood and the so-called Kubo-Landauer approach. This review provides a critical assessment of the advantages and disadvantages in both types of description in particular with regards to interdiffusion effects at interfaces. The illustrations given will not only consist of applications to metal-metal junctions and metal heterojunctions, but also deal with the problem of tunneling of electrons through a vacuum barrier, which in turn is at the very heart of STM spectroscopy. As a further illustration interlayer exchange coupling and electric transport are correlated with each other in order to yield an ab-initio description of exchange biasing in spin valve systems.

9:00 AM *Q3.2

MEAN FREE PATH EFFECTS IN CPP TRANSPORT B.J. Hickey, L. Michez and G.J. Morgan, Department of Physics and Astronomy, E.C. Stoner Laboratory, University of Leeds, Leeds, UNITED KINGDOM; S. Shatz and N. Wiser, Department of Physics, Bar-Ilan University, Ramat-Gan, ISRAEL.

Recently[1] we have shown that the mean free path is a relevant length scale for transport when the current is applied perpendicular to the plane (CPP) of a multilayered sample. Previously it was thought that the spin diffusion length was the only relevant length scale for

CPP transport [2]. In new experiments, we have shown using three magnetic layers of different coercivities, that the field dependence of the magnetoresistance can only be explained by including the mean free path. We have also shown, by varying the thickness of layers, that both the magnitude and the thickness dependence of the magnetoresistance is independent of the spin diffusion length. In this talk we will review the arguments for and against the spin diffusion idea and show that the evidence provided by experiment is in favour of the mean free path argument.

[1] Bozec D. et al PRL 85 1314-1317 (2000) [2] A. Barthelemy, A. Fert and F. Petroff, in Handbook of magnetic materials, ed K.H.J. Bushow Elsevier, Amsterdam

9:30 AM *Q3.3

GIANT MAGNETORESISTANCE VERSUS INTERFACE STRUCTURE IN Fe/Cr SUPERLATTICES. J. Santamaria[a], M.E. Gomez[b], M.C. Cyrille[c], Dept of Physics, University of California-San Diego, CA; J.L. Vicent, U. Complutense, Madrid, SPAIN; K.M. Krishnan, Dept. of Materials Science and Engineering, Seattle, WA; Ivan K. Schuller, Dept of Physics, University of California-San Diego, CA; [a]On leave from Universidad Complutense, Madrid, SPAIN; [b]On leave from Universidad del Valle, Cali, COLOMBIA; [c]Present address IBM Almaden.

We study the connection between giant magnetoresistance measured with the current perpendicular to the layers (CPP GMR) and interface structure in sputtered [Fe/Cr] superlattices to explore the role played by long wavelength roughness (larger than atomic). We have characterized the structure of the superlattices using quantitative X-ray diffraction and quantitative energy filtered transmission electron microscopy (EFTEM) spectra. EFTEM probes the individual interfaces, which allows the simultaneous determination of static and dynamic critical exponents. A statistical analysis of the local interface width for the individual layers shows anomalous non-self-affine roughness characterized by a time dependent local interface width. Varying deposition conditions results in important changes in the critical exponents and roughness characteristic length scales. In addition we have measured independently the CPP resistivity and magnetoresistance in photolithographically prepared samples of well defined geometry. A detailed comparison of structure, magnetism and transport shows that in Fe/Cr superlattices the resistivity is mostly determined by roughness lateral correlation length whereas the magnetoresistance scales with interface width. These results provide the quantitative connection between interface structure and transport and outline the importance of interface scattering in the mechanism of GMR. Work supported by New del Amo Program and DOE We thank S. K. Sinha for useful conversations.

10:30 AM *Q3.4

MAGNETIZATION REVERSAL PROVOKED BY SPIN INJECTION. Jean-Eric Wegrowe, Andrea Fabian, Xavier Hoffer, Travis Wade, Laurent Gravier, and Jean-Philippe Ansermet, Institute of Nanophysics, Ecole Polytechnique Federal de Lusanne (EPFL), SWITZERLAND.

The direct effect of spin injection on magnetization reversal was studied on pillar Co(30nm)/Cu(10nm)/Co(10nm) and Ni nanostructures, of diameter about 60 nm, with different protocols [1]. The samples are characterized by CPP-GMR and AMR effects. The magnetization reversal occurs by well defined jumps at switching fields H_{sw}. DC current injection (R(I) hysteresis), sub-microsecond pulse (ΔH_{max} (I) = H_{sw}-H_{app} curves), after-effect (τ(I,H)), and telegraph noise (τ (I,H)) measurements with nanosecond resolution were performed. The effect of the current is quantified in terms of current driven activation out of a metastable state. The analysis of the data in terms of exchange torque, or spin-transfer, models [2,3] is discussed. However, our observations suggest an interpretation in terms of non- equilibrium relaxation of the spins of the conduction electrons (s electrons), which also involves the d-band electrons responsible for the magnetization (four channel model description). The modulus of the magnetization of the ferromagnetic layer is then not conserved at an interface, due to spin-transfer from the current.

[1] J.-E. Wegrowe, A. Fabian, Ph. Guittienne, X. Hoffer, L. Gravier, T. Wade and J.-Ph. Ansermet 91, 6806 (2002) [2] F. J. Albert, J. A. Katine, R. A. Buhrman, D. C. Ralph, Appl. Phys. Lett. 77 (2000), 3809. [3] J. Grollier, V. Cros, A. Hamzic, J.M. George, H. Jaffes, A. Fert, G. Faini, J. Ben Youssef, H. Le Gall, Appl. Phys. Lett. 78 (2001), 3663.

11:00 AM *Q3.5

MECHANISMS BEHIND THE TEMPERATURE DEPENDENCE OF TUNNELING MAGNETORESISTANCE. Johan Akerman, Motorola, Renu Whig Dave, J. M. Slaughter, Motorola Labs, Physical Sciences Research Laboratories, Tempe, AZ; Igor V. Roshchin, Ivan K. Schuller, Physics Department, UCSD, La Jolla, CA.

The achievement of large Tunneling magnetoresistance (TMR) in FM/AlOx/FM magnetic tunnel junctions (MTJ) is essential for the realization of competitive magnetic random access memory (MRAM). Although zero-bias room-temperature TMR of above 50% can be routinely achieved in such MTJs, TMR is unavoidably reduced at large bias and high temperature. While several mechanisms for the TMR decrease have been proposed and discussed in the literature, the inevitable effects of the temperature dependent electron energy distribution have been largely ignored. An immediate consequence of the electron energy distribution is the thermal smearing of any distinct features in the tunneling data. Based on our analysis of detailed measurements of the differential resistance (dV/dI) and TMR of state-of-the-art MTJs as a function of temperature, we argue that the dominant contribution to the temperature dependence of zero-bias TMR is thermal smearing of the zero-bias anomaly (ZBA). At low finite bias, i.e. when moving away from the ZBA (within a few kT), the temperature dependences of both dV/dI and TMR become weaker. As there are no significant features in the tunneling data outside of |Bias|>0.1V (farther away from the ZBA), thermal smearing has less of an effect, and neither temperature dependence changes significantly with bias. The remaining temperature dependence of TMR can be well described by a temperature dependent spin polarization P(T) with a Bloch law behavior (1-alpha*$T^{(3/2)}$). For optimally oxidized samples (highest TMR), this temperature dependence is weak, and alpha is small. Samples with reduced oxidation time have less TMR and a stronger temperature dependence, i.e. larger alpha. The loss of TMR is due to a weaker spin polarization, and the increase in alpha is attributed to the loss of spin stiffness, both possibly linked to the incompletely oxidized Al at the electrode-barrier interface.

Work supported by the US-DOE and ONR-DARPA

11:30 AM *Q3.6

SPIN TRANSFER IN FERROMAGNET-NORMAL METAL SYSTEMS. Arne Brataas, Harvard University, Lyman Laboratory of Physics, Cambridge, MA.

Mesoscopic ferromagnet-normal metal systems have recently attracted considerable attention. Slonczewski and Berger proposed that a spin-current could cause a switching of the magnetization orientation. The idea is that the spin-current induces a torque, a "spin-torque", on the spins of the conduction electrons, which subsequently transmit this torque to the magnetization. We formulate a theory of spin dependent transport of an electronic circuit involving ferromagnetic elements with non-collinear magnetizations which is based on the conservation of spin and charge current. The theory considerably simplifies the calculation of the transport properties of complicated ferromagnet-normal metal systems. We illustrate the theory by the computing the spin-torque in two and tree-terminal systems with diffusive, tunnel and ballistic junctions. We demonstrate that there is also a reverse mechanism: Precessing ferromagnets are predicted to inject a spin current into adjacent conductors via Ohmic contacts, irrespective of a conductance mismatch with, for example, doped semiconductors. This opens the way to create a pure spin source "spin battery" by ferromagnetic resonance. When the normal metal is a spin sink this "pumping" of spins slows down the precession corresponding to an enhanced Gilbert damping constant in the Landau-Lifshitz equation. Our estimates for permalloy thin films explain the trends observed in recent experiments.

SESSION Q4: MAGNETIC NANOSTRUCTURES

Chairs: Alan S. Edelstein and Thomas Christoph Schulthess
Tuesday Afternoon, December 3, 2002
Room 209 (Hynes)

1:30 PM Q4.1

SPIN POLARIZED TUNNELING AND MAGNETIC PROPERTIES OF MAGNETITE NANOCRYSTAL ARRAYS. Gil Markovich, Pankaj Poddar, Tcipi Fried, School of Chemistry, Tel Aviv University, Tel Aviv, ISRAEL.

This work is aimed at studying both the single nanocrystal and the collective array properties of organically passivated magnetite nanocrystals. Two-dimensional arrays of the nanoparticles coated with oleic acid were prepared at the air-water interface using the Langmuir Blodgett technique [1]. I-V spectra of tunneling junctions consisting of a stack of several particle monolayers show interesting temperature dependence [2]. Surprisingly, the nanocrystals undergo the first-order Verwey Metal-to-insulator transition around 100K, in spite of the large surface to volume ratio. The tunneling spectra show large magnetic field sensitivity giving rise to very large magnetoresistance values at low bias voltages. The magnetic properties of the 2D arrays show significant differences compared to isolated nanocrystals as well as differences from quasi-3D arrays made by stacking several monolayers. AC susceptibility measurements show that the 2D case has unique magnetic behavior due to anisotropic dipolar inter-particle interactions and indicate that collective freezing of magnetization occurs at the close-packed arrays. [1] T. Fried. G Shemer. G. Markovich. Adv. Mater. 13. 1158 (2001). [2] P. Poddar. T. Fried. G Markovich. Phys. Rev. B 65. 172405 (2002).

1:45 PM Q4.2
NANO-GLASSES OF PREVIOUSLY NEVER VITRIFIED CERAMICS AND METALS BY EXPOSURE TO A 2.45 GHz MAGNETIC FIELD. Rustum Roy, Ramesh Peelamedu, Larry Hurtt, Jiping Cheng, Dinesh Agrawal, Materials Research Institute, The Pennsylvania State University, University Park, PA.

True glasses are non-crystalline solids produced by 'rapid' cooling of a liquid. In this paper we report the solid-state transformation from the crystalline to the non-crystalline state as evidenced by bulk XRD and SEM data in ferrites ($NiFe_2O_4$, $CoFe_2O_4$, $FeFe_2O_4$, $ZnFe_2O_4$, $BaFe_{12}O_{19}$, etc.) and a variety of 3d oxides (Mn, Cu, etc.) Glasses of such compositions have never been made. The SEM and TEM data suggest a possible 'melting' on a "nano" scale only, with no macroscopic liquid formation (i.e. sufficient flow) in these compositions, although they have low viscosity melts. This is accomplished by exposing 5 mm diameter, 1 mm thick, samples to a 'pure' magnetic field in a single mode cavity at a 2.45 GHz frequency, for 5 (to 90) seconds. The role of the magnetic field is demonstrated to be the critical element, since in the same equipment at a distance of 3 cm, identical pellets in the E field yield excellent euhedral crystals only. Likewise in a multimode field (albeit at a ten times slower rate) only well crytallized materials appear. All the nano-glass phases are soft magnets.

2:00 PM Q4.3
EFFECT OF NANO-OXIDE IN SPIN-VALVES. Yihong Wu, Nat Univ of Singapore, Dept of ECE and Data Sotrage Institute, SINGAPORE; Kebin Li, Jinjun Qiu, Guchang Han, Ping Luo, Towchong Chong, Data Storage Institute, SINGAPORE.

Since the first report of spin-valves by IBM in 1991, various ways to enhance the performance of the simple spin valves have been explored, which has resulted in various derivatives of the original spin-valves. These include but are not limited to (i) multiple spin-valve (e.g., dual spin-valve), (ii) spin-filter spin-valve, (iii) specular reflection spin-valve, (vi) nano-oxide added spin-valve, and (v) nano-oxide added dual spin-valve. Among them, the nanooxide added spin-valve is reported to be particularly promising for >100 Gbit/in^2 recording applications. So far, in most of the experiments, the nano-oxide has been added to either one or both of the free and pinned layers or in layers adjacent to them. As there are a dozen of magnetic and non-magnetic layers in the latest state-of-the-art spin-valves, it is of importance to find out how the nanooxide will affect the performance of the sensor when it is added other than these traditional locations. We have carried out a systematic study on the effect of oxygen dose during the oxidation process as well as the different locations of the oxides including the use of multiple layers. It was found that the addition of oxygen to the second pinned layer gives best results in terms of MR enhancement and large process window, though a multiple layer of oxides at different locations will improve the performance further under optimum conditions. The results will serve as a useful guideline for spin-valve design and manufacturing.

2:15 PM Q4.4
INERT GAS CONDENSATION OF IRON AND IRON-OXIDE NANOPARTICLES. C. Baker, University of Delaware, Department of Materials Science and Engineering, Newark, DE; S. Ismat Shah, University of Delaware, Department of Materials Science and Engineering, University of Delaware, Department of Physics and Astronomy, Newark, DE, Fraunhofer Center, Newark, DE; K. Hasanain, L. Shah, QUA University, Pakistan; G. Li, K.M. Unruh, University of Delaware, Department of Physics and Astronomy, Newark, DE.

An inert gas condensation (IGC) technique was used to prepare nanometer-sized particles of metallic iron, iron oxide, and mixed phase particles by the evaporation of metallic iron into a flowing inert gas stream. The particles were passivated in an oil bath prior to their removal from the vacuum chamber and consequently could be handled in an atmospheric environment without further oxidation. X-ray diffraction and transmission electron microscopy measurements indicated that, depending on the deposition conditions, mean particles diameters between 10 and 30 nm could be obtained. We will present the results of the process parameter variation on the nanoparticle properties. The results of magnetic properties measurements will also be presented.

2:30 PM Q4.5
SELECTIVE GROWTH OF COBALT NANOCLUSTERS IN DOMAINS OF BLOCK COPOLYMER FILMS AND IN SPIN-COATED INVERSE MICELLES. Jeff Abes, Robert Cohen, Massachusetts Institute of Technology, Dept of Chemical Engineering, Cambridge, MA.

The synthesis of a well-ordered array of monodisperse ferro- or ferrimagnetic nanoparticles for data storage has been of great interest. However, many syntheses have been unable to produce particles above the superparamagnetic size limit, or have problems with particle agglomeration. We have synthesized cobalt nanoparticles large enough (some are 30 nm or more in diameter) for hard magnetism at room temperature in the poly(2-vinyl pyridine) blocks of poly(styrene-b-2-vinyl pyridine) by the thermal decomposition of dicobalt octacarbonyl. We sequester this organometallic into the poly(2-vinyl pyridine) blocks by solvent casting, or by loading reverse micelles with a poly(2-vinyl pyridine) core and then spin coating. Information about particle size and micellar film structure has been obtained using TEM and AFM. Temperature-dependent magnetic behavior (thermally assisted switching) has been characterized using AGM and SQUID.

2:45 PM Q4.6
SYNTHESIS AND CHARACTERIZATION OF NANO-STRUCTURED IRON POWDERS. Heng Zhang, Shihui Ge, Y.D. Zhang, Shiqiang Hui and Zongtao Zhang, Inframat Corporation, Farmington, CT.

An ultrafine magnetic component is essential in order to achieve the exchange coupling in three-dimensional bulk nanostructured magnetic composites. In order to establish a high efficient procedure to fabricate nanostructured iron, co-precipitation, sol-gel and auto-combustion procedures were conducted to synthesize the iron oxide precursors for nanostructured iron. The reduction and grain growth feature of the initial oxides were studied using variable-temperature treatments under a hydrogen-reducing environment. Control the heat-treatment cycle resulted in different grain size for these iron oxides. The effect of the grain size and crystal structure of iron oxides on the grain size of iron and its magnetic property in the sequential reduction has been investigated. The study indicated that maghemite was obtained when using a sol-gel method; auto-combustion led to a hematite, while co-precipitation resulted in a mixture of hematite and maghemite. The cubic maghemite and rombohedrial hematite were reduced to nanostructured iron in hydrogen. The magnetic properties were investigated using a Quantum Design SQUID magnetometer. The magnetic saturated moment was found to depend on both the microstructure and grain size of the nanoscale iron. Using optimal parameters, an ultrafine nanostructured iron with a high-saturated magnetic moment has been achieved. Details will be addressed in this presentation.

3:30 PM Q4.7
TUNNEL SPLITTINGS IN DEUTERATED Mn_{12}-ACETATE SINGLE CRYSTALS. E. del Barco, A.D. Kent, Physics Department, New York University, New York, NY; E.M. Rumberger, D.N. Hendrickson, Department of Chemistry and Biochemistry, University of California, San Diego, La Jolla, CA; G. Christou, Department of Chemistry, University of Florida, Gainsville, FL.

We present an experimental study of the tunnel splittings in single crystals of deuterated Mn_{12}-acetate single molecule magnets. Deuterated material was studied because synthesis leads to high quality single crystals. Landau-Zener measurements have been carried out for different quantum resonances with varied applied magnetic field sweep rates, α, in a regime in which molecules relax by pure quantum tunneling. Beginning from an out of equilibrium magnetization, $M_{initial}$, a resonance is crossed n times at a given α, while the magnetization is continuously recorded using a micro-Hall magnetometer. The relaxation of the magnetization toward the equilibrium magnetization, M_{eq}, is related to the quantum tunnel splitting, Δ_k, at the resonance k through the Landau-Zener formula, $P = 1 \exp(-\pi\Delta_k^2 n/2\nu_k)$, where ν_k is the energy sweep rate in the experiment, and is proportional to α and depends on the studied resonance, k. This method has allowed us to study almost the whole relaxation of the magnetization in only one resonance and extract the corresponding mean tunnel splitting and the distribution of tunnel splittings without a specific theoretical model as to the origin of the tunnel distributions (e.g. line dislocations, solvent disorder, crystal defects, etc.). We have started from different initial magnetizations in order to examine how magnetic dipolar interactions affect the magnetic relaxation. Experiments have also been done at different angles of the applied magnetic field with respect to the easy anisotropy axis of the molecules. We will discuss how the transverse component of the applied field affects the mean tunnel splitting and the distribution of tunnel splittings.

3:45 PM Q4.8
MICROMAGNETIC SIMULATION OF THERMAL EFFECTS IN

MAGNETIC NANOSTRUCTURES. R. Dittrich, V. Tsiantos, T. Schrefl, D. Suess, W. Scholz, H. Forster, J. Fidler, Vienna Univ of Technology, Vienna, AUSTRIA.

Thermal effects become important as the structural size of magnetic elements used in sensors or storage decreases. Thermal fluctuations are a major contribution to the noise of sensors. Thermal activated processes may induce the spontaneous switching of magnetic storage elements. In order to investigate both type of effects two different micromagnetic simulation tools have been developed: (1) An efficient solver for the stochastic Landau-Lifshitz Gilbert equation, and (2) a path method for finding the minimum energy path and energy barrier between stable magnetic states. In sensor elements the thermal fluctuations cause spin wave excitations that can be investigated solving the stochastic Landau-Lifshitz-Gilbert equation. In $150\times100\times5$ nm^3 NiFe elements the main spin wave frequency was 14 GHz. The variance of the normalized magnetization increases from 0.07 to 0.09 as the temperature is increased from 350 K to 500 K. The energy barriers for thermal relaxation of storage elements are calculated using a path finding method. Minimum energy paths are calculated for the transitions between the possible stable domain configurations of thin film elements. Small elements reverse by nonuniform rotation. For small elements the leaf state was identified as local minimum. In the leaf state the magnetization points nearly parallel to the diagonal. In larger submicron elements the preferred reversal mode is the nucleation and expansion of reversed domains. Intermediate domain configurations are local minima, whereas localized reversed domains are saddle points. Energy barriers in thin film elements strongly depend on the strength of the intergrain exchange coupling. If the exchange constant in the intergranular phase is reduced to 5% of the bulk value the energy barrier decreases by about a factor of 1/2. Both the stochastic time integration method and the path finding method use finite element techniques to discretize the equations. Thus complex geometries and various microstructural features like edge roughness and irregularly shaped grains can be taken into account.

4:00 PM Q4.9

MAGNETIC PROPERTIES OF MONOATOMIC COBALT CHAINS IN PLATINUM. Markus Eisenbach, G. Malcolm Stocks, Oak Ridge National Laboratory, Oak Ridge, TN.

Recent advances in the manufacture and characterization of magnetic nanostructures have produced experimental results for high quality monoatomic Cobalt chains on Platinum [P. Gambardella et al., Nature p. 301, vol. 416 (2002)]. Utilizing our fully relativistic real space multiple scattering code we investigate the magnetic properties of this arrangement. For Cobalt chains embedded in fcc Platinum we observe an extended region of spin polarization in the surrounding Platinum with a magnetic moment of the order of $0.3\mu_B$ and an increased Co moment of $\sim 2.1\mu_B$. In addition to investigating the size of the induced moment region, we are interested in the magnetic anisotropy in this system. Furthermore we will address the difference between embedded chains and the experimental situation of chains on a substrate. The research of ME is supported by an appointment at the Oak Ridge National Laboratory administered by the Oak Ridge Institute for Science and Education.

4:15 PM Q4.10

ELECTRONIC STRUCTURE AND MAGNETIC ANISOTROPY ENERGY OF Co_4-BASED SINGLE MOLECULE NANOMAGNET. Tunna Baruah, Department of Physics, Georgetown University, Washington, DC; Mark R. Pederson, Center for Computational Materials Science, Naval Research Laboratory, Washington, DC.

We present our density functional based calculation of electronic structure and magnetic anisotropy energy of different conformers of $Co_4(hmp)_4(CH_3OH)_4Cl_4$ where hmp is deprotonated hydroxymethyl pyridine. The calculations are performed using a massively parallel electronic structure code (NRLMOL). Our calculations have shown that the molecule consists of Co atoms with local moments of S=3/2. This is in accord with the experimental measurement showing a ferromagnetic ordering with a total spin of S=6. We have also calculated the induced orbital moment of this molecule and find it to be small. As an extension of the work discussed in Ref. [1] we will present calculated exchange interactions and the resulting spin excitation function. The experiments predict that this molecule is a strong magnetic with an anisotropy energy of approximately 100K. Our calculations suggest that the second-order anisotropy due to spin orbit coupling is closer to 27-50 K and that it is strongly dependent on the pyridine-pyridine separation. Because of the strong dependence on pyridine placement we have considered the possibility that spin-vibron interactions could strongly perturb the spin-orbit only barrier[2]. Calculations on this effect will be presented. [1] T. Baruan and M.R. Pederson, Chem. Phys. Lett. [2] M.R. Pederson, N. Bernstein and J. Kortus (Submitted).

4:30 PM Q4.11

FABRICATION OF PHOTONIC CRYSTALS AND PLASMONIC WAVEGUIDES WITH $Au@SiO_2$ COLLOIDS AS BUILDING BLOCKS. Yu Lu, Dept of Materials Science & Engineering, Univ of Washington, Seattle, WA, Younan Xia, Dept of Chemistry, Univ. of Washington, Seattle, WA

Gold nanoparticles have been coated with amorphous silica to form spherical colloids with a core-shell structure. The thickness of silica shells could be conveniently controlled in the range of tens to several hundred nanometers by changing the concentration of the sol-gel precursor or the coating time. These core-shell colloids could serve as the building blocks to fabricate photonic devices. In one demonstration, we showed that these core-shell particles could be assembled into long-range ordered lattices (or photonic crystals) over large areas that exhibited optical properties different from those crystallized from silica colloids. Transmission spectra of these crystals displayed both features that correspond to the Bragg diffraction of a periodic lattice and the plasmon resonance absorption of gold nanoparticles. Reflectance spectra taken from these crystals only showed peaks caused by Bragg diffraction. In another demonstration, these core-shell colloids were assembled into chains of different configurations by templating against well-defined channels patterned in thin films of photoresist. As suggested by previous studies, the plasmon coupling between gold cores makes these structures ideal candidates for nanoscale waveguides with lateral mode sizes well below the optical diffraction limit.

SESSION Q5: MAGNETIC PROXIMITY EFFECT

Chairs: Peter Weinberger and Chris Leighton
Wednesday Morning, December 4, 2002
Room 209 (Hynes)

8:30 AM *Q5.1

INDUCED MAGNETISM AT THE INTERFACES OF ANTIFERROMAGNETS. Axel Hoffmann, Materials Science Division, Argonne National Laboratory, Argonne, IL.

With the development of ever more complex magnetic heterostructures consisting of various layers with widely differing magnetic properties a detailed understanding of their magnetic structure becomes paramount. Using polarized neutron reflectometry we addressed two problems that occur at the interfaces of antiferromagnetic materials: first, can the magnetic order in the antiferromagnet induce ferromagnetism in an almost ferromagnetic material such as Pd? Second, does the antiferomagnet in an exchange bias system (consisting of a ferro- and an antiferromagnet) develop a net magnetic moment? To address the first problem we studied epitaxial Pd/NiO bilayers and superlattices with a variety of different crystalline orientations. These samples were prepared with a specific isotope composition in order to enhance the magnetic contrast in our measurements. Nevertheless, no magnetic moment was observed for the Pd layer. In fact an upper limit for any ordered Pd magnetic moment is 0.01 μ_B/Pd atom. On the other hand for a $Co/LaFeO_3$ bilayer in its exchange-biased state we observe a significant asymmetry in the polarized neutron reflectometry for positive and negative saturation. This implies that the magnetization depth profile differs on either side of the ferromagnetic hysteresis loop. The observed asymmetry is consistent with a net magnetic moment forming in the antiferromagnetic layer. Simulations of the neutron reflectometry suggest that this moment is sizable (approximately 2 μ_B/unit cell) and confined closely to the interface (within the first three monolayers). This work was done in collaboration with M. Fitzsimmons (Los Alamos National Laboratory), J.W. Seo, H. Siegwart, J. Fompeyrine, and J.-P. Locquet (IBM Zurich), and J.A. Dura, and C.F. Majkrzak (NIST Gaithersburg). The financial support for this work came from DOE, BES-DMS under contract No. W-7405-Eng-36 and W-31-109-Eng-38, and the Los Alamos National Laboratory through its directors funded postdoctoral fellowship program.

9:00 AM *Q5.2

ORIGIN OF THE MAGNETIC PROXIMITY EFFECT. Miguel Kiwi, Facultad de Física, Pontificia Universidad Católica de Chile, Santiago, CHILE.

The magnetic proximity effect has attracted the attention of theorists and experimentalists for at least three decades.[1] Lately, the relevance of the effect for the development of nanodevices has revived interest on the subject. Here we review how the field has evolved, centering our attention on metal-metal and metal-insulator systems. We describe, and critically compare, the different theoretical approaches that have been put forward, as well as their limitations. Finally, an evaluation of the relationship between existing theories and available experimental results is attempted.

Supported by FONDECYT, Chile under grant #8990005.
[1] M.J. Zuckermann, *Solid State Comm.* **12**, 745 (1973).

9:30 AM *Q5.3
ORIGIN OF SPIN POLARIZATION IN A SEMICONDUCTOR INTERFACED WITH A FERROMAGNET. L.J. Sham, C. Ciuti, J.P McGuire, Dept of Physics, University of California-San Diego, La Jolla, CA.

Significant progress has been made by a number of groups recently in the injection of spin from a ferromagnet into a semiconductor. Experiments by Awschaloms group [1] also demonstrated the polarization of electron and nuclear spins by excitation with linearly polarized light of the electrons in a semiconductor interfaced with a ferromagnet. We show that reflection of semiconductor electrons on the Schottky barrier with a ferromagnet generates spin polarization. Model calculations indicate that a number of features of the experiments may be qualitatively explained. Moreover, from the wave mechanics origin of the spin generation by reflection, it follows that spin polarization in the semiconductor is possible if the electron wave function can tunnel through the barrier to be influenced by the exchange polarization in the ferromagnet. The proximity of a ferromagnet may be used to generate or alter the spin polarization of electrons in the semiconductor. Investigations of designs of spintronics devices utilizing ferromagnetic gates (as an alternative to the magnetic source and drain) will be reported. Work supported by DARPA/ONR N0014-99-1-1096, NSF DMR 0099572, Swiss National Foundation, and a graduate fellowship by California Institute for Telecommunications and Information Technology. [1] R.K. Kawakami et al., Science 294, 131 (2001). R.J. Epstein et al., Phys. Rev. B 65, 121202 (2002).

10:30 AM Q5.4
GROWTH MODES AND MAGNETOTRANSPORT PROPERTIES IN THIN FILM La-Ca MANGANITES. Z. Sefrioui, M. Varela, A. Asenjo, C. Leon, J. Santamaria, A. de Andres[a] and M. Garcia-Hernandez[a], GFMC, Depto. Fisica Aplicada III, Universidad Complutense de Madrid, SPAIN; [a]Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, SPAIN.

We report on the growth of ultrathin $La_{0.7}Ca_{0.3}MnO_3$ films by high pressure pure oxygen dc sputtering. This technique combines a slow deposition rate (0.13 A/s) with high growth temperature (900 °C) providing a very thermalized and ordered growth. Using this technique, films of thickness varying between 2 and 200 nm have been grown on different substrates ($SrTiO_3$ (STO), $LaAlO_3$ (LAO), MgO, $SrLaAlO_3$ (SLAO), etc). Different degree of lattice mismatch causes changes in the growth mode: While a 3D island-like mode is found for samples grown on substrates with large mismatch (no matter in plane tensile or compressive) (MGO and SLAO), a 2D coherent growth mode is found for samples grown on substrates with smaller mismatch, like STO. Interestingly, 2D samples do not show significant dependence of the ferromagnetic critical temperature with thickness. On the other hand 3D samples display a reduction of the Curie temperature when thickness is reduced. This show that the role played by epitaxial strain has been overestimated so far, when T_c changes with thickness in relatively thick films (100 nm) have been attributed to it. Work supported by CAM and CICyT MAT 2000 1468

10:45 AM Q5.5
SPIN DEPENDENT TRANSPORT IN MANGANITE-BASED STEP-EDGE JUNCTIONS. Catherine Dubourdieu, Alexei Bossak, Patrick Chaudouet, Jean-Pierre Sénateur, Laboratoire des Matériaux et du Génie Physique, St Martin d'Hères, FRANCE; Thierry Fournier, CRTBT, Grenoble, FRANCE.

The half-metallic character of the manganese oxide $La_{0.7}Sr_{0.3}MnO_3$ makes this material of particular interest for spin electronic devices. A low-field magnetoresistance is observed in heterogeneous materials such as polycrystalline films or heterostructures. We have investigated the properties of step-edge junctions based on this material. Two types of step-edge structures were prepared. The step was either prepared directly on a $SrTiO_3$ (001) substrate by ion beam etching or on an insulating $NdMnO_3$ film deposited on a $SrTiO_3$ (001) substrate. In the latter case, the step was etched using a wet chemical route. A $La_{0.7}Sr_{0.3}MnO_3$ film was then deposited on the prepared surface. All films were deposited by injection metalorganic chemical vapor deposition. For both types of junctions, a low-field magnetoresistance is observed when the magnetic field is applied in the film's plane. However, their temperature dependences are different. For the best junctions, the low-field magnetoresistance (<0.2 T) is still significant at room temperature (about 1 %). As expected, measurements performed under a magnetic field applied perpendicularly to the substrate's plane only reveal the CMR effect of the manganite film.

11:00 AM Q5.6
SPIN DEPENDENT TRANSPORT IN MAGNETITE/DOPED MANGANITE BASED TRILAYER JUNCTIONS. Guohan Hu, Yuri Suzuki, Cornell Univ, Dept of Materials Science and Engineering, Ithaca, NY; Rajesh Chopdekar, Cornell Univ, Dept of Applied and Engineering Physics, Ithaca, NY.

Epitaxial trilyar junctions composed of half metallic magnetite (Fe_3O_4) and doped magnanite ($La_{0.7}Sr_{0.3}MnO_3$) electrodes were fabricated and characterized. The junctions exhibited junction magnetoresistance (JMR) as high as -25% in a field of 4kOe. The improvement of the JMR over that observed in previous epitaxial magnetite junctions is attributed to the choice of the iso-structural $CoCr_2O_4$ barrier, which minimizes the structural disorder at the barrier/Fe_3O_4 interface. Inverse magnetoresistance confirms the theoretically predicted negative spin polarization of Fe_3O_4. The I-V characteristic fit well to a model where the conduction mechanism is inelastic hopping transport through N=2 and N=3 localized states. The JMR versus temperature curve exhibits a peak around 60K. This behavior is explained in terms of the paramagnetic to ferromagnetic transition of the $CoCr_2O_4$ barrier.

11:15 AM Q5.7
CUPRATE/FERROMAGNETIC OXIDE SUPERLATTICES. Hanns-Ulrich Habermeier, Georg Cristiani, MPI-FKF, Stuttgart, GERMANY.

The physical properties of the perovskite-type oxide RuSr2GdCu2O8 have been recently discussed in the view of a simultaneous occurrence of ordering mechanisms leading to superconductivity and ferromagnetism in different parts of the unit cell. In order to explore some peculiarities of these compounds such as presence or absence of the Meissner state we have prepared superlattices of oxides that are known to be either ferromagnetic [La.67Ca.33MnO3 and SrRuO3] or superconducting [YBa2Cu3O7]. The two ferromagnetic materials have been choosen due to their different coupling mechanisms leading to ferromagnetic order. Superlattices of different periodicity serve as model systems for the understanding of the peculiarities of the RuSr2GdCu2O8 system and are used to compare their properties with those of our single phase epitaxially grown RuSr2GdCu2O8 thin films. The YBCO/LCMO as well as YBCO/SRO superlattices have been grown by pulsed laser deposition with individual layer thickness ranging from 4 to 200 unit cells for the YBa2Cu3O7 and 10 to 500 unit cells for the La.67Ca.33MnO3 and SrRuO3, respectively. The films are characterized by X-ray diffraction analysis, Raman spectroscopy, susceptibility and transport measurements. Whereas simple heterostructures [single layer La.67Ca.33MnO3 and single layer YBa2Cu3O7 50 nm thickness each] reproduce the intrinsic properties of the constituent material rather well [Curie temperature 250K superconducting transition at T = 70K] there are some novel effects emerging due to the coupling between the layers observed in the superlattices. Superlattices with individual thickness of the constituent materials of 4 nm e.g. show a reduced Curie temperature of 120K and a superconducting transition temperature of 60K. Lowering the temperature a reentrant normal state occurs at T = 25K. Switching off the electronic interlayer coupling by the introduction of insulating SrTiO3 spacer layers leads to the intrinsic critical temperatures. Furthermore, the coupling between the supperconducting and ferromagnetic layers is different for the LCMO and SRO system. For the explanation of the results several concepts are discussed the frame of ferromagnetic interlayer coupling and superconducting proximity effect.

11:30 AM Q5.8
SPIN DYNAMICS IN NICKEL NANOWIRES ARRAYS. Kornelius Nielsch, Ralf B. Wehrspohn, Ulrich Gösele, Max-Planck-Institute of Microstructure Physics, Halle, GERMANY; Zhi-Kui Wang, Meng-Hau Kuok, Ser-Choon Ng, Department of Physics, National University of Singapore, SINGAPORE; David J. Lockwood, Institute for Microstructural Sciences, Ottawa, CANADA; Michael G. Cottam, Department of Physics and Astronomy, University of Western Ontario, London, CANADA.

The next generation of magnetic media is foreseen to comprise vertically spin-aligned systems of magnetic wires or dots at much reduced nanometer dimensions. We use highly or-dered alu-mina pore channel arrays as tem-plates for the fabrication of magnetic nanowire arrays with a periodicity of 65 (180 Gbit/in^2) and 100 nm (75 Gbit/in^2) and pore diameters between 25 and 55 nm. In analogy to polycrystallites, there are domains in which the nanowires are hexagonally arranged. They are extended over more than ten lattice periods. Because of the high degree of order of the nanowires arrays, we detect a squareness of ≈ 100% and coercive fields of 1200 Oe in the direction of the nanowires. The complete filling of the alumina pore structure with nickel and the small deviation of the nanowire diameter (< 8%) allow, for the first time, detailed Brillouin light scattering studies of electrodeposited nickel nanowires. The dynamic properties of spins in nanomagnets govern the time scale of the magnetization reversal, which is of fundamental significance for determining the writing time in magnetic storage devices. Our Brillouin data on spin waves in the nickel nanowires reveal strong quantization effects on their bulk magnetic properties and hint at the subtle magnetic interplay between closely spaced nanowires. The results of this investigation show that it will be critically important to take account of these effects, both for fundamental science and in future developments of quantum nanomagnet technology.

11:45 AM Q5.9

STUDY OF THE LOW FIELD MICROWAVE RESPONSE IN YTTRIUM ALUMINATES DILUTELY DOPED WITH MANGANESE. Rakhim Rakhimov, David Jones, George Loutts, Norfolk State University, Center for Materials Research, Norfolk, VA.

Microwave response near zero magnetic field was observed in $YAlO_3$ and $CaYAlO_4$ crystals doped with Mn in concentrations ranging from 0.05 to 2 atomic %. The response is due to non-resonant microwave absorption, which co-exists with normal electron paramagnetic resonance (EPR) absorption due to different paramagnetic valence states of manganese. Mn^{2+} and Mn^{4+} charge states were identified in Mn-doped $YAlO_3$, and Mn^{2+}, Mn^{4+} and Mn^{5+} in Mn-doped $CaYAlO_4$. The low field response has the opposite phase with respect to the paramagnetic absorption. This shows that Mn-doped $YAlO_3$ and $CaYAlO_4$ exhibit magnetically induced microwave absorption, which has a minimum at zero magnetic field and increases with the applied magnetic field. This effect is similar to microwave magneto-resistance effects observed in managanite perovskites, where spin-dependent electron tunneling occurs between ferromagnetically coupled manganese ions in different valence states. We show, however, that in the present case of diluted paramagnetic systems magneto-induced microwave losses are due to intramolecular spin-dependent tunneling, where the central paramagnetic ion does not change its charge state and spin-dependent charge migration occurs in the first coordination sphere of paramagnetic ion. Evidences are presented that this ion is Mn^{2+} exhibiting the highest electron spin $S = 5/2$.

SESSION Q6: IN-ROOM POSTER SESSION NANOSTRUCTURED MAGNETS

Wednesday Afternoon, December 4, 2002
2:00 PM
Room 209 (Hynes)

Q6.1

REORIENTATION TRANSITION OF Fe/Cu(111) THIN FILMS. B. Ujfalussy, University of Tennessee, Knoxville, TN; J. Shen, Oak Ridge National Laboratory, Oak Ridge, TN; G.M. Stocks, Oak Ridge National Laboratory, Oak Ridge, TN.

We present first-principles calculations using the Fully Relativistic Screened Korringa-Kohn-Rostoker method to determine the orientation of magnetization of Fe/Cu(111) overlayers. We find, that in very good agreement with recent experiments, there is a reorientation transition at about 2 layers from out of plain to in plane magnetization. We extend the theoretical studies to discuss various covered samples and interfaces. This work is supported by the DOE-OS through BES-DMSE and OASCR-MICS under contract number DE-AC05-00OR22725 with UT-Battelle LLC. Calculations are performed at CCS-ORNL and at NERSC.

Q6.2

DOUBLE QUANTUM WIRE TUNNEL TRANSPORT AND MAGNETIC RESPONSE. Anatoly Yu. Smirnov, D-Wave Systems Inc., Vancouver, BC, CANADA; Lev G. Mourokh, Norman J.M. Horing, Department of Physics and Engineering Physics, Stevens Institute of Technology, Hoboken, NJ.

We analyze electron transport and the induced magnetic moment of a biased semiconductor tunnel-coupled parallel double quantum wire system. The wires are tunnel-coupled to leads in a series arrangement, with their parallel lengths and associated continuous spectrum taken in the direction perpendicular to the lead-to-lead current. Electrons sequentially tunnel from the left lead to the left wire, tunnel from the left wire to the right wire, and, finally, tunnel from the right wire to the right lead. Tunneling from wire to wire is taken to be much faster than tunneling between leads and wires. We consider a magnetic field applied perpendicular to the plane of the parallel wires, facilitating the analysis of the magnetic response properties of the system. We derive and solve the equations of motion for the double-wire electron Green's function using the transfer-tunneling Hamiltonian formalism. The solution is employed to determine the current through the structure and the average magnetic moment of the double-wire system induced by the applied magnetic field. The induced magnetic moment is seen to vary between diamagnetic and paramagnetic, depending on the bias voltage and temperature. These properties of the double-wire structure introduce a mechanism for the lead-to-lead bias control of the induced magnetic moment of this system.

Q6.3

METAL/SELF ASSEMBLED MONOLAYERS/METAL JUNCTIONS FOR MAGNETOELECTRONICS APPLICATIONS. Yevgeniy A. Ovchenkov, Bernard Doudin, Department of Physics and Astronomy, University of Nebraska-Lincoln, Lincoln, NE; Chunjuan Zhang, Jody Rodepenning, Department of Chemistry, University of Nebraska-Lincoln, Lincoln, NE.

Self-assembled monolayer (SAM) films on solid surfaces are investigated as potential candidates for magnetic tunnel junctions, to be used in new spintronics devices. Thiols are well-known systems forming dense and uniform SAM layers on a surface of metals [1]. They are interesting alternatives to oxide films, making sharper interfaces, and avoiding reduction/oxidation processes at the interface. The possibility to vary the end groups of these molecules allows us to tailor the chemistry for optimizing the interfaces. The main difficulties for making trilayers systems around SAMs are the defects in their packing and the translation of molecules during the synthesis of the top metallic electrode. These factors often lead to electrical shorts. We investigate two types of geometries for the junctions. The first involves planar electrodes patterned by photolithography of several tens of mm2 area. The second uses template synthesis in nanoporous membranes to reduce the junction area to less than 0.01 mm2. We report the synthesis of junctions involving several types of SAMs using electroless deposition for the top metal electrode. Electroless deposition is activated with Pd clusters obtained or by evaporation or by chemical reduction of Pd-based catalyst. This method allows us to obtain in a reproducible way junctions that are stable at room temperature without indications of shortcuts. Low-temperatures investigations reveal strong non-linearity in the IV curves and an increase of resistance with decreasing temperatures. Strong zero bias anomalies observed at low temperatures are attributed to a Coulomb blockade associated with Pd clusters used for activation of electroless deposition. [1] For a review, see, for example, F. Schreiber, Progr. In Surf. Sci. 65 (2000) 151

Q6.4

CHEMICALLY FUNCTIONAL ALKANETHIOL STABILIZED MAGNETIC NANOPARTICLES. David Fleming, Mike Napolitano, Mary Elizabeth Williams, The Pennsylvania State University, Department of Chemistry, University Park, PA.

A series of magnetic core/shell nanoparticles (Fe, Co, Ni encased in an Au shell) have been prepared using the inverse micelle synthetic technique. The nanoparticles have been functionalized with alkanethiolate ligands, which prevent aggregation, enable solubility in a range of solvents (both hydrophobic and hydrophilic), and permit subsequent derivatization (e.g., via ligand exchange). These nanoparticles are monodisperse (<15%) with diameters between 3 and 7 nm. We have utilized place exchange to impart chemical functionality to the nanoparticles by attaching either (1) thiol-derivatized redox moieties (e.g., ferrocene) or (2) alkanethiols with terminal reactive groups such as alcohol, amine and carboxylic acid. The particles are characterized using high resolution transmission electron microscopy (HRTEM), electron dispersive x-ray spectroscopy (EDS), atomic force microscopy (AFM), and magnetic force microscopy (MFM). This paper presents our preliminary investigations of the voltammetry of magnetic core/shell nanoparticles. Electrochemical experiments in the presence of an applied magnetic field and utilizing both diamagnetic and ferromagnetic electrodes have been employed to examine field effects on particle diffusion and functional redox activity. We have additionally studied the chemically-specific binding of the nanoparticles to two-dimensional, patterned surfaces. For example, using microcontact printed arrays of aminoethanethiol on Au surfaces (or aminopropyl trimethoxysilane on glass), standard peptide coupling agents are used to form amide linkages to carboxylic acid functionalized nanoparticles. These patterned assemblies are interrogated using AFM and MFM.

Q6.5

MAGNETIC PROPERTIES OF AMORPHOUS METAL/POLYMER NANOCOMPOSITES. Vincent H. Hammond, James M. O'Reilly, Nonmetallic Materials Division, University of Dayton Research Institute, Dayton, OH.

Nano-sized, amorphous metal powders can be easily fabricated via the chemical reduction of aqueous metal salt solutions. The resulting powders are typically amorphous and tend to possess attractive soft magnetic properties. This combination of fine size and soft magnetism makes the particles ideal for incorporation in thin film magnetic devices. As a first step in exploring this approach to device fabrication, thin film composite rings containing either Fe-Co-B or

Fe-Nd-B powders have been produced by cold pressing and curing polymer-coated powders. The resulting magnetic performance of the rings will be discussed as a function of particle composition and content. In particular, the ability to optimize the magnetic response through careful selection of the initial salt solution will be detailed. Potential applications of such devices will also be discussed.

Q6.6

MAGNETIC PROPERTIES OF Ni NANOPARTICLES EMBEDDED IN AMORPHOUS SiO_2. Fabio Coral Fonseca, Gerardo Fabian Goya, Renato de Figueiredo Jardim, Instituto de Física, Universidade de São Paulo, São Paulo, SP, BRAZIL; Reginaldo Muccillo, Centro Multidisciplinar de Desenvolvimento de Materiais Cerâmicos CMDMC, CCTM-Instituto de Pesquisas Energéticas e Nucleares, São Paulo, SP, BRAZIL; N.L.V. Carreño, Elson Longo, and Edson R. Leite, Centro Multidisciplinar de Desenvolvimento de Materiais Cerâmicos CMDMC, Departamento de Química, Universidade Federal de São Carlos, São Carlos, SP, BRAZIL.

A modified sol-gel technique was used to synthesize nanocomposites of $Ni:SiO_2$ which resulted in Ni nanoparticles embedded in a SiO_2 amorphous matrix. Transmission electron microscopy TEM analysis were performed to study the structure and morphology of the magnetic powders. The Ni particles were found to have a good dispersion and a controlled particle size distribution, with average particle radius of ~ 3 nm, as inferred by TEM analysis. A detailed characterization of the magnetic properties was done through magnetization measurements M(T,H) in applied magnetic fields up to ± 7 T and for temperatures ranging from 2 to 300 K. The superparamagnetic (SPM) behavior of these metallic nanoparticles was inferred from the temperature dependence of the magnetization. The blocking temperature T_B, as low as 20 K, was found to be dependent on the Ni concentration, increasing with increasing Ni content. The SPM behavior above the blocking temperature T_B was confirmed by the collapse of M/M_S vs. H/T data in universal curves. These curves were fitted to a log-normal weighted Langevin function allowing us to determine the distribution of magnetic moments. Using the fitted magnetic moments and the Ni saturation magnetization, the radii of spherical particles were determined to be close to ~ 3 nm, in excellent agreement with TEM analysis. Also, an important result was obtained from magnetic hysteresis loops that were found to be symmetric along the field axis with no shift via exchange bias, suggesting that Ni particles are free from an oxide layer. In addition, for the most diluted samples, the magnetic behavior of these Ni nanoparticles is in excellent agreement with the predictions of randomly oriented and noninteracting magnetic particles when the temperature dependence of the magnetic anisotropy is considered. This was confirmed by the temperature dependence of the coercivity field that obeys the relation $H_C(T) = H_{C0}[1 - (T/T_B)^{1/2}]$ below T_B with H_{C0} ~ 780 Oe.

Q6.7

MAGNETOTRANSPORT AND HALL EFFECT IN ULTRA-THIN COLOSSAL MAGNETORESISTANCE FILMS. Trevor W. Olson, Dept of Physics, Jonathan C. Eser, Yuri Suzuki, Dept of Materials Science and Engineering, Cornell Univ, Ithaca, NY.

Doped perovskite manganites, so-called colossal magnetoresistive materials, exhibit magnetic and transport properties that are particularly sensitive to lattice distortions. They are double exchange ferromagnets in which the metal insulator transition coincides with a magnetic transition. We have investigated the magnetics and magneto transport in ultra thin films of CMR materials of $La_{0}.7Sr_{0}.3MnO_3$ (LSMO) that are below the critical thickness of 400Angstroms. Our ultra-thin LSMO films are grown on (100) $LaAlO_3$ substrates and are compressively strained. Since the films are thinner than the Matthews-Blakesley critical thickness, the films are believed to be elastically deformed. Magneto conductance and Hall effect measurements of the ultra thin LSMO films show two anomalies: (i) the conductivity of the film goes to zero before the thickness goes to zero at low temperature and (ii) the anomalous Hall effect reverses sign in ultra thin films at low temperature. Measurements of magnetoresistance (MR) versus temperature in a range of film thicknesses also shed light on the origin of these observed anomalies. The MR vs. T plot, sign reversal of the anomalous Hall effect and the nonzero intercept of the conductance vs. T plot are all consistent with the existence of an interface and/or surface layer which is significantly more insulating, and thus different in nature from bulk single crystal LSMO.

Q6.8

SPIN DEPENDENT TRANSPORT IN COLOSSAL MAGNETORESISTANCE TRILAYERS. Lisa Berndt Alldredge, Dept of Applied & Engineering Physics, Yuri Suzuki, Dept of Materials Science & Engineering, Cornell Univ, Ithaca, NY.

Colossal magnetoresistance materials have been predicted to have complete spin polarization and are ideal candidates for electrodes of a magnetic tunnel junction since they maximize the junction magnetoresistance (JMR). So far, tunnel junctions based on CMR materials, such as $La_{0.7}Sr_{0.3}MnO_3$ (LSMO), have been one of the most successful epitaxial oxide tunnel junctions with JMR values as high as 80% reported for these junctions at 4.2K. However JMR decreases rapidly with increasing temperature and vanishes by room temperature, and it is thought that the quality of the interface greatly affects the properties of these tunnel junctions. For our work, we have chosen a barrier layer that is isostructural to the electrodes in order to grow the trilayer films coherently and to minimize strain by only changing one cation species. The top and bottom layers were LSMO, and the barrier layers were $La_{1-x}Ca_xMnO_3$ (LCMO) with x=0.1, 0.3 and 0.65. These films were deposited onto $SrTiO_3$ substrates using pulsed laser deposition. X-ray diffraction data shows that both LSMO and LCMO grow epitaxially. For the range of compositions of LCMO, the lattice mismatch between LSMO and LCMO is about 1.9% or less. For x=0.1 and 0.3, LCMO is a paramagnetic insulator within a limited temperature range. For x=0.65, LCMO is a paramagnetic insulator at high temperatures but is an antiferromagnetic insulator at lower temperatures. In-plane transport measurements of trilayer films show bulk CMR behavior at high field and anisotropic magnetoresistance at low field that depends on the orientation between the current and the magnetic field. Vertical transport measurements show nonlinear current-voltage curves.

Q6.9

LARGE MAGNETORESISTANCE IN $Ni_{1-x}Ti_xS$. P. Chen, Y.W. Du, S.P. Wong, Electronic Engineering Department of Chinese University, Hong Kong, CHINA, Physics Department of Nanjing University, Nanjing, CHINA.

Large magnetoresistance (MR) was observed in $Ni_{1-x}Ti_xS$ (x = 0, 0.02, 0.04, and 0.06), MR=1530% at 268K for x=0, MR=1220% at 240K for x= 0.02, MR=830% at 200K for x=0.04, and MR=410% at 158K for x=0.06 in magnetic field 4T. The large MR is due to magnetic field-induced magnetic and electrical transition from antiferromagnetic (AFM) nonmetal phase to paramagnetic (PM) metal phase.

Q6.10

NONSTOICHIOMETRY OF EPITAXIAL $FeTiO_{3+\delta}$ FILMS. Tatsuo Fujii, Makoto Sadai, Masakazu Kayano, Makoto, Nakanishi, Jun Takada, Okayama Univ, Dept of Applied Chemistry, Okayama, JAPAN.

Ilmenite, $FeTiO_3$, is of particular interest because of its unique magnetic and semiconducting properties. It forms a solid solution with α-Fe_2O_3 in the entire range and makes a half-metallic ferrimagnet. Recently we have prepared well-crystallized epitaxial $Fe_{2-x}Ti_xO_{3+\delta}$ films on α-Al_2O_3(001) substrates by reactive MBE methods [1]. However the deposited films had large oxygen nonstoichiometry and had inferior half-metallic properties in comparison with those for the stoichiometric bulk samples. In this paper, we precisely examined oxygen nonstoichiometry of epitaxial $FeTiO_{3+\delta}$ films as a function of the oxygen partial pressure (PO_2) during the deposition and discussed structural and magnetic properties of the films. Sample films were prepared on α-Al_2O_3(001) substrates by helicon plasma sputtering with base pressure of 10^{-7} Pa. A sintered $FeTiO_3$ target was used for the sputter deposition at substrate temperature of 1173 K. The PO_2 during the deposition was monitored by using a Q-mass filter. Deposition rate and thickness were about 0.1nm/s and 100 nm for all films, respectively. After the deposition the sample films were examined by x-ray diffraction (XRD), magnetization measurement (VSM), conversion electron Mössbauer spectroscopy (CEMS). The oxygen nonstoihiometry of $FeTiO_{3+\delta}$ films was very sensitive to the PO_2. The films deposited at PO_2=1.0x10^{-6} Pa was nearly stoichiometric while the films deposited at PO_2=1.5x10^{-6} Pa was fully oxidized to $FeTiO_{3.5}$. The nonstoichiometric $FeTiO_{3.5}$ had defect structure where the cations and cation vacancies randomly occupy interstitial and substitutional sites in the corundum-related α-Fe_2O_3 structure. [1] T. Fujii, et al., Mat. Res. Soc. Symp. Proc., vol. 623 (2000), p. 191.

Q6.11

ENHANCEMENT OF THE THERMAL STABILITY OF MAGNETIC TUNNEL JUNCTIONS WITH Co/TiN/Co ARTIFICIAL ANTIFERROMAGNET PINNED LAYER. S.-H. Han, W.-C. Jeong, Z.-Z. Wang and S.-K. Joo, Seoul National Univ, School of Material Science and Engineering, Seoul, KOREA.

Magnetoresistive random-acess memory (MRAM) experience near 400°C high temperature processes during manufacturing. So, the thermal stability of magnetic tunnel junction (MTJ) near 400°C is requisite MRAM application. However, the tunnel magnetoresistance (TMR) signal is decreased after annealing above 300~ 350°C because

Mn diffuses into the pinned ferromagnetic layer. In this study, the thermal stability of MTJ with Co/TiN/Co, a new artificial antiferromagnetic (AAF) layer, was investigated and compared with Co/Ru/Co AAF. MTJs based on Co/AlO$_x$/Co/TiN(Ru)/Co/NiMn were prepared by RF magnetron sputtering and AlO$_x$ was oxidized by O_2 plasma. Successive annealing was performed at from 200°C to 400°C. Co/Ru/Co AAF showed higher antiferromagnetic coupling force than Co/TiN/Co AAF. So, TMR ~~signal~~ was ~~higher~~ at room temperature in MTJ with Co/Ru/Co AAF than Co/TiN/Co AAF. According to increasing annealing temperature, but, TMR decay was more significant in junction with Co/Ru/Co AAF. TMR signal was significantly decreased in junction with Co/Ru/Co AAF up to 350°C annealing. On the other hand, junction with Co/TiN/Co AAF still presented a high TMR signal. This difference could be explained in terms of blocking Mn diffusion more efficiently by TiN/Co interface than Ru/Co interface.

SESSION Q7: EXCHANGE BIAS

Chairs: Gernot Guntherodt and Mark D. Stiles
Thursday Morning, December 5, 2002
Room 209 (Hynes)

8:30 AM *Q7.1

COMPLEX EXCHANGE ANISOTROPY IN Fe/MnF2 BILAYERS. E. Dan Dahlberg[a], I.N. Krivorotov[a], C. Leighton[b], J. Nogus[c], and Ivan K. Schuller[d]; [a]Department of Physics, University of Minnesota, Minneapolis, MN; [b]Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, MN; [c]Instituci Catalana de Recerca i Estudis Avanats (ICREA) and Departament de Fisica, Universitat Autnoma de Barcelona, Bellaterra, SPAIN; [d]Department of Physics, University of California-San Diego, La Jolla, CA.

Although discovered over 45 years ago, a microscopic understanding of the Ferromagnetic/Antiferromagnetic (F/AF) exchange coupling which arises at the interface between a ferromagnet and an antiferromagnet has been lacking. It has been recently understood that the almost exclusive use of hysteresis loops to study the phenomenon has limited our understanding of the exchange coupling with the development of techniques using the anisotropic magnetoresistance (AMR) [1] to investigate the exchange coupling between a ferromagnet and antiferromagnet. Since its initial use, the AMR technique has developed into a powerful probe of the F/AF exchange coupling. We have used the AMR technique to measure the angular dependence of the exchange anisotropy energy in Fe/MnF2 bilayers. The data were used to develop an analytical model of exchange anisotropy. The model successfully explained the recently measured [2] threefold and the fourfold anisotropy terms in Fe/MnF2 bilayers originate from a partial domain wall in the MnF2 layer. We are also able to separately determine the fraction of uncompensated interfacial spins in the antiferromagnetic layer and the interfacial exchange coupling energy between spins in the ferromagnet and in the antiferromagnet.

[1] B.H. Miller and E. Dan Dahlberg, Appl. Phys. Lett. 69,3932-3934 (1996).
[2] I. N. Krivorotov, C. Leighton, J. Nogues, I.K. Schuller, and E.D. Dahlberg Phys. Rev. B 65(RC), 100402, (2002).
This work supported in part by the University of Minnesota MRSEC, NSF/DMR-9809364.

9:00 AM *Q7.2

EXCHANGE BIAS AND COERCIVITY. M.D. Stiles, and R.D. McMichael, National Institute of Standards and Technology, Gaithersburg, MD.

The magnetic coupling between the ferromagnetic layer and the antiferromagnetic layer in an exchange bias bilayer leads to a number of interesting and useful effects including a shift in the hysteresis loop of the ferromagnetic layer. Many of these effects involve irreversible behaviors, the most prominent being the increased coercivity. We describe a simple model that exhibits both reversible exchange-bias behavior and irreversible processes that contribute to the coercivity. The model describes a polycrystalline system where the grains of the antiferromagnet are considered to be randomly oriented and uncoupled except via their mutual coupling to the ferromagnetic layer. The coupling to each antiferromagnetic grain gives a local unidirectional anisotropy (easy direction) to the ferromagnetic layer that contributes to the loop shift when the antiferromagnetic order is stable. The model reveals two contributions to the coercivity. In some grains, the antiferromagnetic order can be unstable ~~depending on~~ the temperature and the magnetic history of the sample. Switching the antiferromagnetic order of these grains during reversal is one contribution to the coercivity. Also, the grain-to-grain random orientation of the easy direction leads to frustration of ferromagnetic magnetization during reversal even when the antiferromagnetic order in each of the grains is stable. This contribution to the coercivity is a common feature of magnetically inhomogeneous films. The simplicity of the model considered here allows the interplay of reversible and irreversible processes to be studied over a wide range of parameters. Interesting results include training effects, asymmetric reversal, and multiple peaks in the coercivity as a function of temperature. We compare these effects to related effects seen in other measurements ~~like rotational~~ torque and ferromagnetic resonance.

9:30 AM *Q7.3

EXCHANGE BIAS STUDIES WITH MAGNETIC DICHROISM. Boris Sinkovic, Univ of Connecticut, Storrs, CT.

(ABSTRACT NOT AVAILABLE)

10:30 AM *Q7.4

SIMULATIONS OF THE DOMAIN STATE MODEL. U. Nowak, A. Misra and K.D. Usadel, Institut fuer Physik, Gerhard-Mercator Universitaet Duisburg, Duisburg, GERMANY.

Exchange bias (EB) is a horizontal shift of the hysteresis loop observed for a ferromagnetic (FM) layer in contact with an antiferromagnetic (AFM) layer. Even though this effect is well known since many years its microscopic origin is still under debate. It is obvious, however, that EB is related to the spin structure of the antiferromagnet. Hence, for a fundamental understanding of EB a detailed knowledge of the physics of the AFM layer is inevitable. Recently, we introduced a microscopic model [1] where domains are formed in the volume of the AFM stabilized by dilution. These domains become frozen during the cooling procedure carrying a remanent net magnetization which causes and controls EB. Monte Carlo simulations of the model [1-3] show a strong dependence of the EB on the degree of dilution in agreement with recent measurements on Co/CoO bilayers [1,4] and a variety of facts associated with EB can be explained, like positive EB after cooling in strong magnetic fields, the temperature dependence of EB, its dependence on the AFM layer thickness, the training effect, and the influence of the anisotropy of the AFM, among others.
[1] P. Miltenyi, M. Gierlings, J. Keller, B. Beschoten, G. Guentherodt, U. Nowak and K. D. Usadel, Phys. Rev. Lett. 84, 4224 (2000).
[2] U. Nowak, A. Misra, and K. D. Usadel, J. Appl. Phys. 89, 7269 (2001), and J. Magn. Magn. Mat. 240, 243 (2002).
[3] U. Nowak, K. D. Usadel, P. Miltenyi, J. Keller, B. Beschoten, G. Guentherodt, Phys. Rev. B, in press.
[4] J. Keller, P. Miltenyi, B. Beschoten, G. Guentherodt, U. Nowak, K. D. Usadel, Phys. Rev. B, in press.

11:00 AM Q7.5

EFFECT OF ANISOTROPY ON THE CRITICAL ANTIFERROMAGNET THICKNESS IN EXCHANGE BIASED BILAYERS. M.S. Lund, Dept. of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, MN; W.A.A. Macedo, Physics Department, University of California-San Diego, La Jolla, CA; Kai Liu, Department of Physics, University of California-Davis, Davis, CA; J. Nogues, Inst Catalana de Recerca i Estudis Avançats (ICREA) and Departament de Fisica, Universitat Autonoma de Barcelona, Bellaterra, SPAIN; Ivan K. Schuller, Physics Department, University of California-San Diego, La Jolla, CA; C. Leighton, Dept. of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, MN.

Exchange biased antiferromagnet/ferromagnet bilayers exhibit a critical antiferromagnetic thickness, below which the exchange bias effect disappears. In addition to being a phenomenon of fundamental interest this has technological implications in the magnetic recording industry. The simplest models of exchange bias predict that this critical thickness is primarily determined by the antiferromagnet anisotropy, although this has not yet been confirmed experimentally. The dependence of exchange bias on antiferromagnet thickness has been measured in FeF_2/Fe and MnF_2/Fe bilayers. The two fluoride systems have identical crystal and spin structures, similar lattice constants, but anisotropy fields that differ by a factor of 20. Hence, by comparing the antiferromagnetic layer thickness dependence of the exchange bias in the two systems we are able to directly establish the effect of the antiferromagnet anisotropy. We find that the critical antiferromagnet thickness for the onset of exchange biasing is an order of magnitude larger for the more anisotropic fluoride, confirming the often-used assumption that the anisotropy dictates the critical thickness. By measuring the temperature dependence of the exchange bias and the structural morphology of the layers we are able to prove that the effects we observe are not due to the blocking temperature ~~thickness dependence or the onset of discontinuity~~ in thin antiferromagnet layers. Work supported by DoE and NSF (UCSD); NSF MRSEC and Office of the Vice-President for Research (UMN).

11:15 AM Q7.6

EXCHANGE BIAS AND TRAINING EFFECT IN POLY-

CRYSTALLINE ANTIFERROMAGNETIC/FERROMAGNETIC BILAYERS. D. Suess, T. Schrefl, J. Fidler, Vienna University of Technology, AUSTRIA, R.L. Stamps, J.V. Kim, University of Western Australia, Crawley, AUSTRALIA.

Exchange bias and training effect in fully compensated antiferromagnet/ferromagnet bilayers are explained with a simple micromagnetic model. The model ~~assumes no defects~~ except for grain boundaries, and coupling is due to spin flop at a perfect interface. Micromagnetic simulations on a mesoscopic length scale show that a weak exchange interaction between randomly oriented antiferromagnetic grains and spin flop coupling at a perfectly compensated interface are sufficient to support exchange bias. Unlike previous partial wall models, the energy associated with the unidirectional anisotropy is stored in lateral domain walls located between antiferromagnetic grains. This mechanism leads naturally to a training effect during magnetization loop cycling. Simulated annealing using a Metropolis Monte Carlo algorithm is applied to mimic field cooling in the simulations. For the subsequent calculation of hysteresis loops the Landau-Lifshitz Gilbert equation is solved. Micromagnetic simulations are performed for IrMn/NiFe bilayers. As a function of the thickness of the antiferromagnet the bias field shows a maximum for a thickness of 22 nm. For decreasing antiferromagnetic thickness the domain wall energy approaches zero. For large thicknesses the high anisotropy energy hinders switching of the antiferromagnetic grains resulting in weak bias. Starting from the field cooled state as initial configuration a bias field of $\mu_0 H_b = 7.7$ mT is obtained assuming a antiferromagnetic layer thickness of 20 nm, a ferromagnetic layer thickness of 10 nm, and a grain size of 10 nm. The next hysteresis cycle shows a reduction of the bias field by about 65 %. This training effect occurs at zero temperature and appears because the domain configuration in the antiferromagnet is strongly field dependent through the orientation of the ferromagnet. Each cycle through the magnetization loop brings the antiferromagnet closer to a type of dynamic equilibrium in which the coercive field no longer changes with each additional cycle and the loop area remains constant. In our simulations, this equilibrium appeared after about four cycles.

11:30 AM Q7.7
ROTATING ANISOTROPIES WITHOUT SUPERPARAMAGNETIC GRAINS IN EXCHANGE BIAS SYSTEMS. Thomas C. Schulthess, Oak Ridge National Laboratory, Computer Science and Mathematics Division and Center for Computational Sciences, Oak Ridge, TN.

Much of the present understanding of dissipation in ferro-antiferromagnet (F-AF) bilayers is based on a model by Fulcomer and Charap [1] and is attributed to superparamagnetic grains in the antiferromagnet. This idea has been used by Stiles and McMichael [2] to explain a constant shift in ferromagnetic resonance spectra with a rotating anisotropy which is caused by such superparamagnetic grains. However, similar dissipative effects can be observed in AF-F bilayers with single crystalline AF. We have modified the microscopic Heisenberg model of AF-F bilayers [3] to include random exchange and anisotropic exchange across the AF-F interface and analyze the net coupling of the F with regard to the AF easy axis for different random interfacial exchange configurations. For the case where there is no anisotropic exchange, we find that the net coupling direction transitions from being parallel to the AF easy axis in the case of small domains to perpendicular alignment when the domains are large. In the transition region the coupling direction varies randomly between different configurations of the interfacial exchange. When anisotropic exchange is included in the calculations there is no collinear coupling even for the smallest domain sizes. With these findings can be used to explain dissipative effects in single crystalline AF-F. The rotating coupling direction is not attributed to superparamagnetic gains in the AF but to unfrozen domain walls in the antiferromagnet that give rise to new random interfacial exchange configurations and thus allow the net coupling directions to follow the ferromagnet moments. Work supported by DOE-OS through BES-DMSE and OASCR-MICS under Contract No. DE-AC05-00OR22725 with UT-Battelle LLC. [1] E. Fulcomer and S. H. Charap, J. Appl. Phys. 43, 4190 (1972). [2] M. D. Stiles and R. D. McMichael, Phys. Rev. B. 59, 3722 (1999). [3] T. C. Schulthess and W. H. Butler, Phys. Rev. Lett. 81, 4516 (1998).

11:45 AM Q7.8
EXCHANGE BIAS FLOP IN EPITAXIAL FeF_2/Co BILAYERS. Hongtao Shi, David Lederman, Physics Department, West Virginia University, Morgantown, WV.

We have measured the angular dependence of the exchange bias field (H_E) in epitaxial (110) FeF_2 (AF)/Co (F) bilayers ~~at 20 K, in which~~ Co is polycrystalline. A large H_E is observed after the sample is field-cooled along the FeF_2 easy axis. Two loops with the same H_E magnitude but of opposite sign were observed after the cooling field was applied 90° to the AF easy axis. Changing the cooling field direction to 91° causes the sample to acquire a significant positive H_E parallel to the AF easy axis. This indicates that the anisotropy in the AF layers is crucial in determining the interface coupling in the AF/F bilayers.

SESSION Q8: APPLICATIONS OF MAGNETIC NANOSTRUCTURES
Chairs: E. Dan Dahlberg and Johan Akerman
Thursday Afternoon, December 5, 2002
Room 209 (Hynes)

1:30 PM *Q8.1
ADVANCES IN MAGNETORESISTIVE RANDOM ACCESS MEMORY (MRAM). Brad N. Engel, Motorola Labs, Tempe, AZ.

Rapid advances in portable communication and computing systems are creating an increasing demand for nonvolatile random access memory that is both high-density and high-speed. Existing solid-state technologies are unable to provide all of the needed attributes in a single memory solution. A new technology, Magnetic Random Access Memory (MRAM) based on magnetoresistive tunneling, has the potential to perform as a universal solution. MRAM is based on the integration of a magnetic device with standard silicon-based microelectronics. This technology promises to provide a unique memory that combines non-volatility, speed and endurance. The large magnetoresistance ratio (MR) and the tunable resistance of magnetic tunnel junction (MTJ) material have made it the magnetoresistive material of choice for MRAM cells. We have addressed the initial feasibility concerns by demonstrating MR>50%, 5% resistance uniformity and reproducible switching over 200mm wafers integrated with a 0.6 micron CMOS process. We have demonstrated a low power 1Mb MRAM based on a 1-Transistor and 1-MTJ (1T1MTJ) bit cell. MTJ elements are integrated with CMOS using copper interconnects cladded with a high permeability layer, which focuses magnetic flux toward the MTJ devices reducing the power needed for programming the bits. The 25mm2 1Mb MRAM circuit has 50ns address access and consumes 24mW at 3.0V and 20MHz. Recent advances in materials, magnetic behavior, process integration and circuit design will be presented. This work was supported in part by DARPA.

2:00 PM *Q8.2
RECENT DEVELOPMENT OF MAGNETIC RECORDING HEADS. Mitsumasa Oshiki, Atsushi Tanaka, Storage System Laboratories, Fujitsu Laboratories Ltd., Atsugi, Kanagawa, JAPAN.

The magnetic recording density of hard disk drive (HDD) becomes higher to the twice in a year. The higher recording density is performed by many technologies. One of the driven technologies is magnetic recording head technology. Progress in the development of giant magnetoresistive (GMR) spin-valve materials and high sensitivity spin-valve read heads has allowed a continuous increase of areal recording density in hard disk drives. In this presentation, we would like to review the evolution of the spin-valve films and spin-valve heads. The spin-valve films are classified as follows; top type spin-valve, bottom type synthetic ferrimagnet spin-valve, bottom type single specular spin-valve, and bottom type double specular spin-valve. We have successfully demonstrated 106 Gbpsi magnetic recording using double specular spin-valve heads in 2001. For ultra-high-density recording over 100 Gbpsi, much higher-sensitive read heads are required and a tunnel magnetoresistive (TMR) head is a strong candidate to realize the high sensitivity. However, because the TMR head is a relatively high impedance device, it faces some shortcomings such as limitation of the operating frequency and large Johnson and shot noise. Another candidate for the ultra-high-density recording head is a current-perpendicular-to-plane (CPP) head using giant magnetoresistive (GMR) films. Recently, half-metal device or spin-polarized-current device with junction structure are paid much attention because of their potentiality for ultra-high-sensitive heads. In this presentation, we will also mention recent results on these junction type devices and discuss for future read head technologies.

3:00 PM *Q8.3
PATTERNED MAGNETIC MEDIA: MAGNETIC PROPERTIES, RECORDING, AND FABRICATION BY IMPRINTING. G.M. McClelland, C.T. Rettner, M. Albrecht, M.W. Hart, S. Anders, T. Thomson, M.E. Best, and B.D. Terris, IBM Research Division, Almaden Research Center, San Jose, CA.

Patterning magnetic media into isolated magnetic islands is a promising strategy for increasing magnetic recording density toward 100 Gbit/cm^2, while avoiding the thermal instability of fine-grained continuous media. To form test samples for understanding the magnetic and recording properties of magnetic islands, a focused ion beam has been used to create arrays of magnetic islands in CoPtCr films. Islands appear as a single domain when they are below a critical size of around 130 nm, and the switching field distribution is sharpened over that of the unpatterned film. In thermal decay measurements with no applied magnetic field, continuous films revealed a decay rate of 1.4% per decade, while the islands were thermally stable. The thermal decay is interpreted in terms of a Stoner-Wohlfarth model incorporating patterning-induced changes to the switching volume and demagnetizing field. A quasi-static write/read tester with a giant magnetoresistive head was used to study the read and write performance on patterned and unpatterned media. We demonstrated writing and reading of individual islands at densities up to 31 Gbit/cm^2, and observed that patterning dramatically reduces transition position jitter and increases the signal-to-noise. A significant lattitude in the position of the write field was observed for correctly writing the patterned islands. A commercially useful lithography for patterning magnetic media must achieve resolution several times better than modern optical lithography at a lower cost. We have used nanomolding for producing 55-nm-diameter magnetic islands over 3-cm wide areas. A master pattern of silicon dioxide pillars was used to form a flexible polymeric mold, which can conform to the roughness and curvature of the substrate. This mold was used to pattern a photopolymer resist film on silicon dioxide. Etching leaves pillars, onto which a CoPt multilayer film was evaporated, forming magnetic islands isolated by the pillar geometry.

3:30 PM *Q8.4
MAGNETIZATION DYNAMICS OF PERPENDICULARLY MAGNETIZED DOTS INSIDE A SOFTER MAGNETIC MATRIX.
Claude Chappert, Thibaut Devolder, Mohamed Belmeguenai, Dafine Ravelosona, Veronique Mathet, Institut d'Electronique Fondamentale, UMR CNRS 8622, Universite Paris-Sud, Orsay, FRANCE; Y. Suzuki, Y. Yokoyama, National Institute of Advanced Industrial Science and Technology, Electronics Institute, Tsukuba, JAPAN; H. Bernas, Centre de Spectrometrie Nucleaire et de Spectrometrie de Masse, UMR CNRS 8609, Universite Paris-Sud, Orsay, FRANCE; Jacques Ferre, Jacques Miltat, Laboratoire de Physique des Solides, UMR CNRS 8502, Universite Paris-Sud, Orsay, FRANCE.

Patterned media are considered as a way to drastically improve storage density in hard disks. We have proposed (1) to use light ion beam irradiation through a lithographic mask, in order to produce a planar patterned media ideal for the head flyability. In parallel, we have shown that light ion beam irradiation is a very powerful tool to optimize media magnetic properties (2). We will report our latest results in this area. We have more specifically tested the magnetization reversal properties of perpendicularly magnetized dots in a matrix of weaker magnetic anisotropy. For that we have used He^+ ion irradiation through a SiO_2 mask to pattern arrays of nanodots in Co/Pt multilayers or $CoPt_3$ alloy film. Perpendicular magnetic anisotropy in such films can be precisely tuned by irradiation. Static magnetometry measurements and Magnetic Force Microscopy show that magnetization reversal in the dots proceeds by injection of domain wall from the "soft" matrix inside the "hard" dot, which induces a very weak dispersion of coercivity. Very specific behaviours have been observed at high speed (sub-nanosecond regime), by using Extraordinary Hall Effect to follow the magnetization reversal of a dot patterned by irradiation inside a Hall cross. By comparing to micromagnetic calculations, those effects can be attributed to the influence of the soft matrix. (1) T. Devolder et al., Appl. Phys. Letters 74, 3383 (1999). (2) T. Devolder et al., Phys. Rev. B64, 064415 (2001).

4:00 PM *Q8.5
QUANTUM COMPUTATION: FROM BRAGG REFLECTIONS TO DECOHERENCE ESTIMATES.
Peter Pfeifer, Dept. of Physics, University of Missouri, Columbia, MO.

A survey of the principles of quantum computation is presented [1]. The survey discusses qubit manipulation, exponential parallelism from polynomial hardware, fast quantum algorithms, quantum error correction, general hardware requirements, and experimental milestones. A compact description of the quantum Fourier transform to extract the periodicity of an input state, the key step in Shors factoring algorithm, provides an explicit example of how state evolution along many classical computational paths in parallel produces fast algorithms, and how constructive interference similar to Bragg reflections in x-ray crystallography selects relevant computations by quantum interference. In the second part of the talk, a variational principle with error bounds for time-evolving states [2] is used to estimate switching times of logic gates and the decoherence time, at which the computer becomes entangled with the environment. A lower bound for a gate to fail due to interactions with the environment is obtained which requires only the interaction between the computer and the environment and the time-evolving state in the absence of any interaction. [1] P. Pfeifer, in: McGraw-Hill Yearbook of Science and Technology 2002, pp. 294-298. [2] P. Pfeifer and J. Frhlich, Rev. Mod. Phys. 67, 759 (1995).

4:30 PM Q8.6
THE MEMS FLUX CONCENTRATOR: A DEVICE FOR IMPROVING MAGNETIC SENSORS.
Alan S. Edelstein, Gregory A. Fischer, Army Research Laboratory, Adelphi, MD.

The MEMS flux concentrator, a device for minimizing the effect of 1/f noise in magnetic sensors is described. In its static configuration, the MEMS flux concentrator's is similar to that usually employed with flux concentrators, i.e., soft magnetic materials are used to increase the field at the position of the magnetic sensor. The difference is that the MEMS flux concentrator is driven by electrostatic fields to perform oscillatory motion. This oscillatory motion modulates the field at the position of the sensor at a frequency that is twice the drive frequency. The magnetic sensors will detect at the modulation frequency and will be unaffected by pickup at the drive frequency. The modulation of the magnetic field has the effect of shifting the operating frequency from the high noise region for low frequency magnetic sensor to a higher frequency region where the noise can be two orders of magnitude lower. Two designs are presented, one in which there is an oscillatory motion of the flux concentrators about a torsional suspension and another in which a comb drive is used to obtain 15-20 micron oscillatory in-plane motion. The later design has two advantages. First, using a comb drive makes it much easier to design a layout for a practical device that provides enough space on the chip between the flux concentrators for the magnetic sensor. Second, the motion of the flux concentrators in the design using the comb drive is easier to model because the force is independent of the displacement. By a suitable choice of parameters, one can adjust the oscillatory frequency to be above 10 kHz and the amplitude of the magnetic field modulation to be greater than 3. Progress in fabricating the device will be presented.